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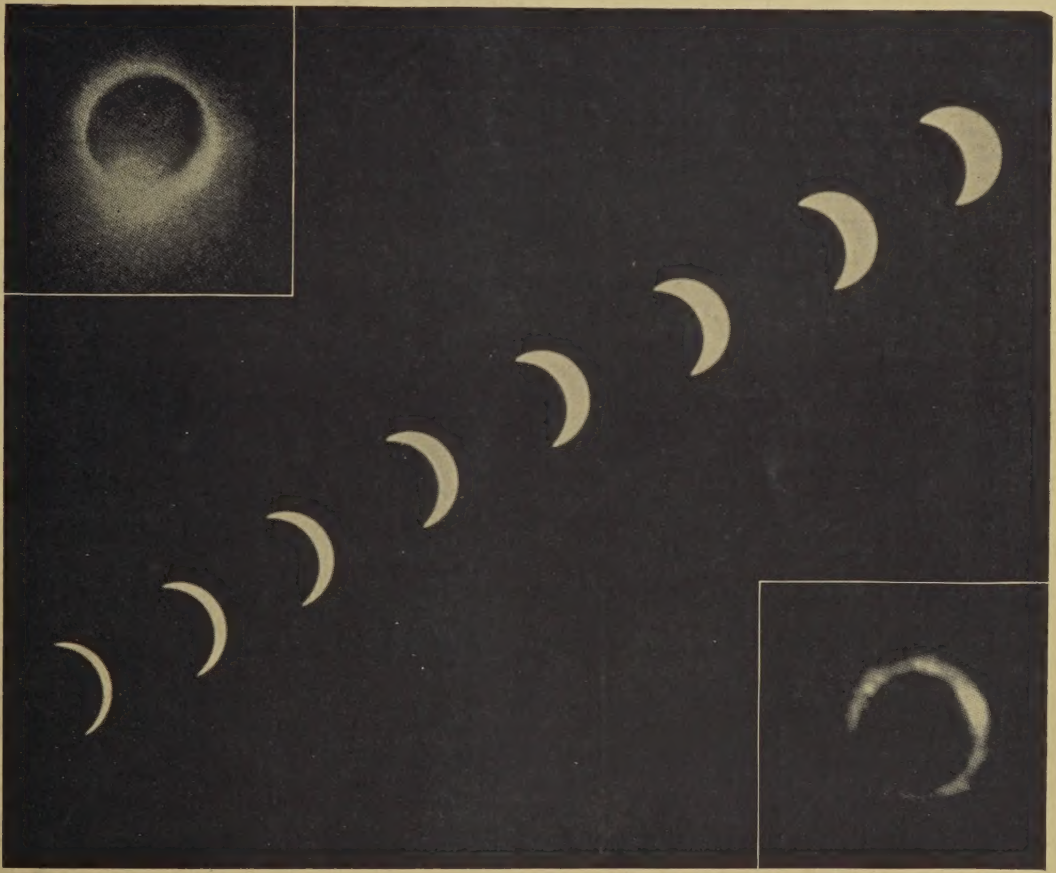


WHEN THE MOON INTERFERED WITH THE SUN'S BROADCASTING

The diagonal series of exposures from the lower left to the upper right shows a number of stages in the concluding phase of the solar eclipse, as taken on a single photographic plate by a "still" camera, shifting the position of the camera during the intervals between exposures.

The insert at the upper left is of the total eclipse and shows a "diamond ring" effect.

The lower insert, also of the total eclipse, was enlarged from a "movie" film.

All these photographs were taken in New York City on the 24th of last January by the New York Edison Co. This Company, and other Public Utility Companies in and about New York City, co-operated in making observations of the shadow path and of the effect of the eclipse on the service loads. *(See page 151)*

In This Issue:

Eclipse
Electric Trucks
Picking Managers
Automatic Substations
Phase Angle Correction Factors
X-rays
Dielectrics
Ethereal Waves
Street Illumination
Hyperboloidal Reflectors

HEAT BALANCE

A Modern Power Plant Problem

THE new catalog, **"Wheeler Evaporators,"** includes a present day study of the relation of evaporators to Power Plant Heat Balance, a question of vital interest to executives and engineers who wish to reduce power plant costs by providing pure distilled boiler feed make-up in the most efficient way.

Heat balance diagrams of actual installations in such modern power plants as Delaware (Philadelphia Electric Co.), Hales Bar (Tennessee Electric Power Co.), and Seal Beach (Los Angeles Gas & Electric Corp.), illustrate the methods which have obtained the best economy under various conditions.

Other topics discussed are:

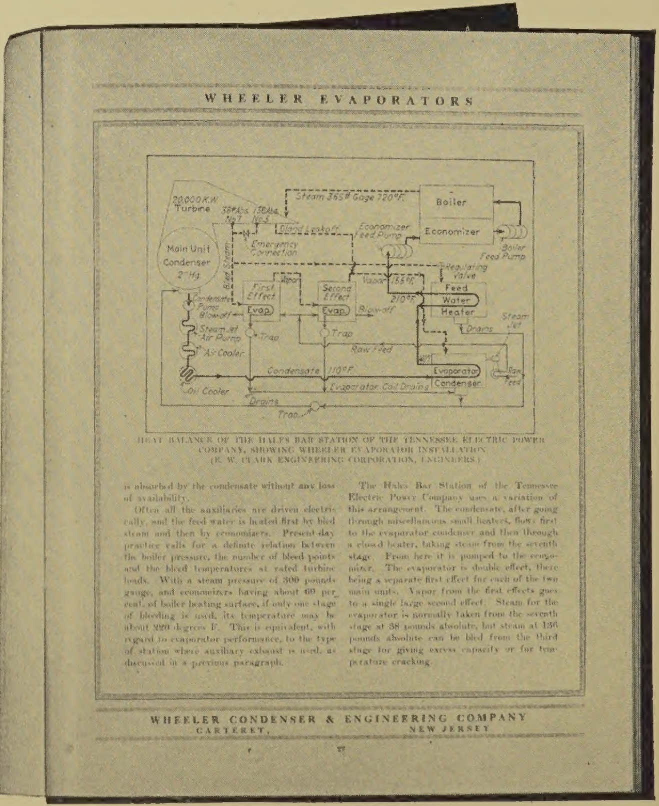
ADVANTAGES OF DISTILLED FEED WATER

TYPES OF EVAPORATORS FOR LOW AND HIGH PRESSURES

CHARACTERISTICS OF FILM AND SUBMERGED TUBE EVAPORATORS.

CHARACTERISTICS AND ECONOMY OF MULTIPLE-EFFECT EVAPORATORS.

If you are interested in obtaining boiler feed water which will not scale, corrode, foam or prime, or want the latest information on heat balance, you should write for Bulletin G-117.



WHEELER EVAPORATORS

HEAT BALANCE OF THE HALES BAR STATION OF THE TENNESSEE ELECTRIC POWER COMPANY, SHOWING WHEELER EVAPORATOR INSTALLATION
(E. W. CLARK ENGINEERING CORPORATION, ENGINEERS)

is absorbed by the condensate without any loss of availability.

Often all the auxiliaries are driven electrically, and the feed water is heated first by bled steam and then by economizers. Present-day practice calls for a definite relation between the boiler pressure, the number of bleed points and the bleed temperatures at rated turbine loads. With a steam pressure of 300 pounds gauge, and economizers having about 60 per cent. of boiler heating surface, if only one stage of bleeding is used, its temperature may be about 220 degrees F. This is equivalent, with regard to evaporator performance, to the type of station where auxiliary exhaust is used, as discussed in a previous paragraph.

The Hales Bar Station of the Tennessee Electric Power Company uses a variation of this arrangement. The condensate, after going through miscellaneous small heaters, flows first to the evaporator condenser and then through a closed heater, taking steam from the seventh stage. From here it is pumped to the economizer. The evaporator is double effect, there being a separate first effect for each of the two main units. Vapor from the first effects goes to a single large second effect. Steam for the evaporator is normally taken from the seventh stage at 38 pounds absolute, but steam at 136 pounds absolute can be bled from the third stage for giving excess capacity or for temperature cracking.

WHEELER CONDENSER & ENGINEERING COMPANY
CARTERET, NEW JERSEY

27

WHEELER PRODUCTS INCLUDE

- CONDENSERS-ALL TYPES
- COOLING TOWERS-HEATERS
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- EXPANSION JOINTS
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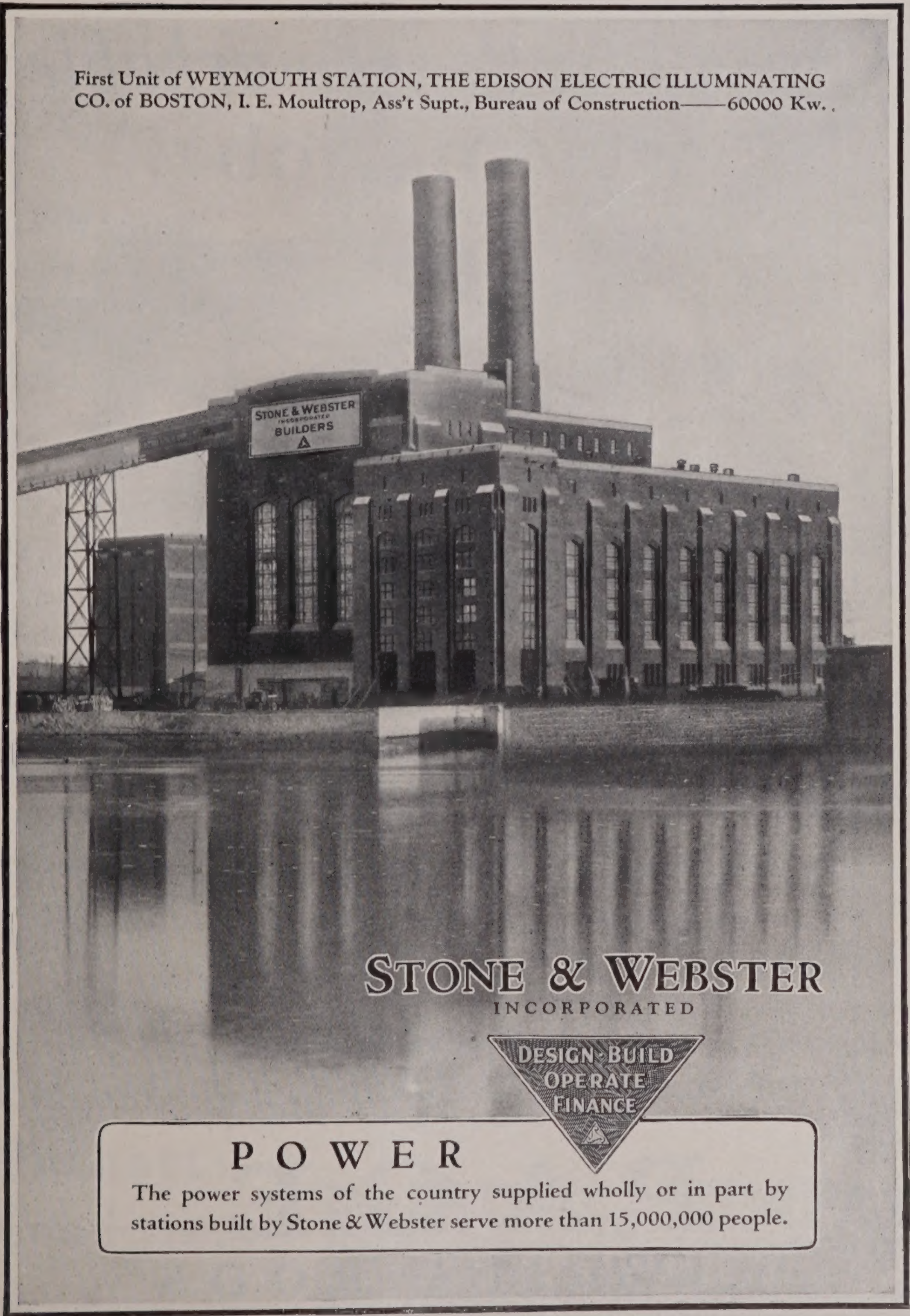

First Unit of WEYMOUTH STATION, THE EDISON ELECTRIC ILLUMINATING CO. of BOSTON, I. E. Moultrop, Ass't Supt., Bureau of Construction——60000 Kw.

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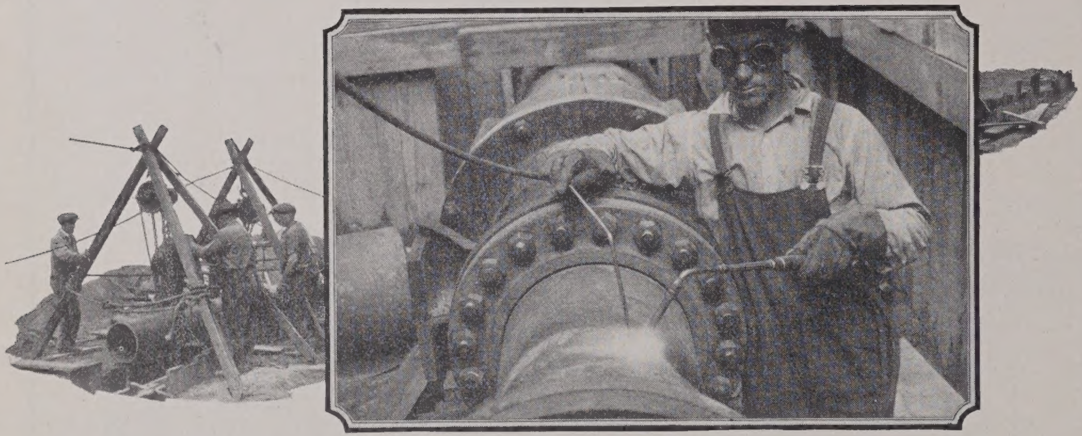
The power systems of the country supplied wholly or in part by stations built by Stone & Webster serve more than 15,000,000 people.

Cleveland's *remarkable* welding job



PAGE-ARMCO WELDING RODS, used to weld 6000 ft. of 16″ steel pipe ½″ thick, pressure steam line of the Cleveland Electric Illuminating Company, Cleveland

6000 *feet of* 16*-inch high pressure steam line*

EACH welded joint has to stand 500 lbs. test. Five pounds of added metal is applied to each joint.

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Rods are a small part of welding cost. Can you *ever* afford to take chances—use any but the best? Try PAGE-ARMCO, time the job, and inspect it and test it.

PAGE also makes high carbon rods—rods of all types for gas, electric and automatic welding. Write for illustrated folder telling how better rods cut welding cost. No obligation. A card will do.

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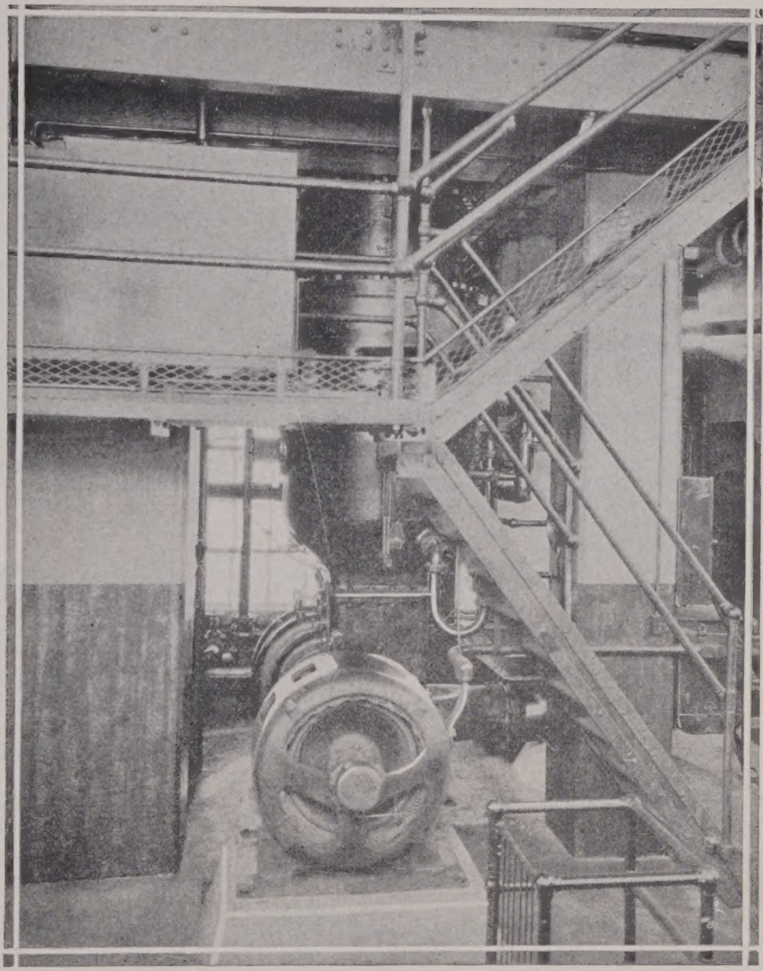

Elliott-Ehrhart Low Level Jet Condenser serving 2,500 kv-a. turbine in the Storrs Colliery plant of the Glen Alden Coal Co. An Elliot-Ehrhart Condenser, to serve a 12,500 kw. turbine, is being installed in the Nanticoke Colliery.

Elliott-
Ehrhart
Condensers

Users of Elliott-Ehrhart Condensers, when installing additional Condenser Equipment, have practically without exception purchased another Elliott-Ehrhart outfit.

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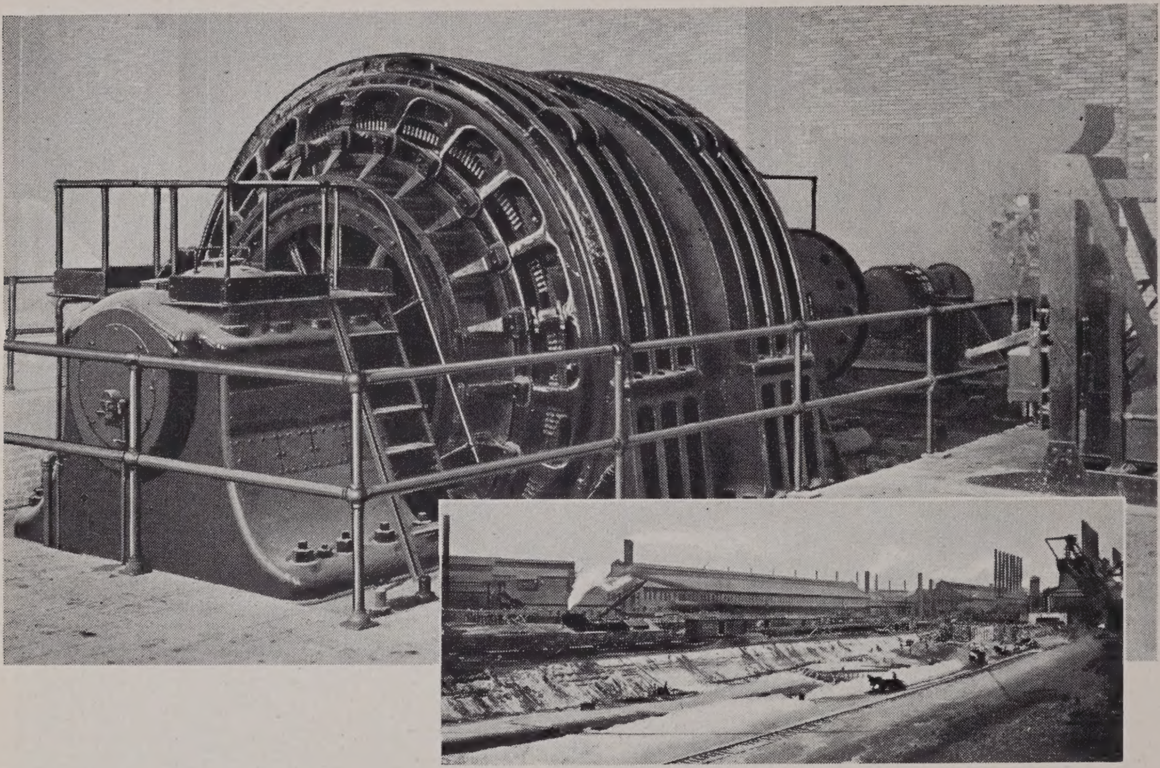
C-267a



On the largest blooming mill motor in the country

NATIONAL Pyramid Brushes are the choice of the engineers responsible for the performance of the largest blooming mill motor in the United States. This motor has two commutators in series, 900 volts DC on each, total 1800 volts, current 9000 amperes. Starting from rest, the motor is capable of accelerating to 120 RPM in one direction, then reversing to 120 RPM in the opposite direction in six seconds. Momentarily, the motor will develop 22,000 H.P. at 50 RPM.

National Pyramid Brushes give sparkless commutators on this giant machine. The commutators are in excellent shape, and the brushes have a long life.

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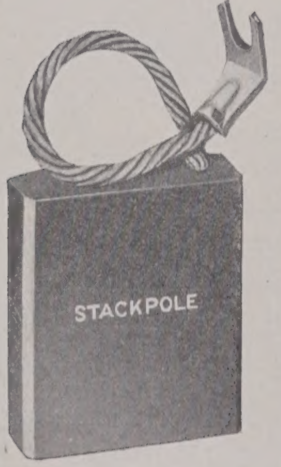
The Mark of the Thoroughbred—
Like the "Sterling" mark on silver



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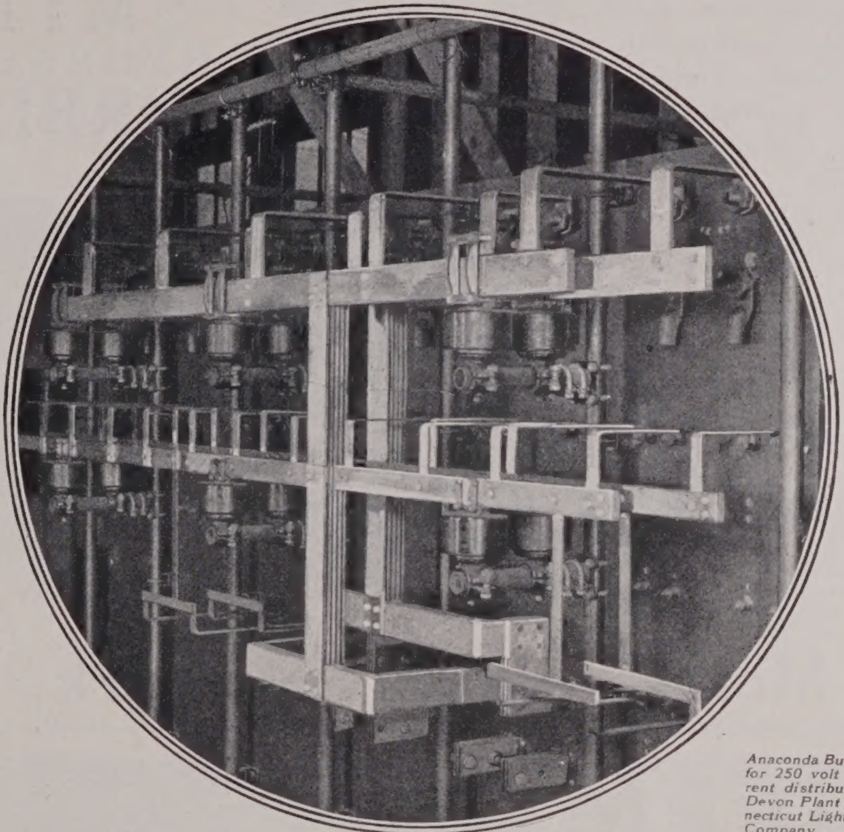
A good horse, a Stackpole Carbon Brush—thoroughbreds both.

Service has brought the Stackpole Carbon Brush high honors from the entire electrical industry. Its unflagging dependability—wrought by the uniformity of its composition—and the diversity of its types rears it to the position to meet every carbon brush requirement.

After actual tests and arduous trials many companies have recognized the true worth of the Stackpole Brush and have made it part of their standard equipment.

Stackpole catalog No. 8 tells the story of the complete Stackpole line.

STACKPOLE
carbon brushes



Anaconda Bus Bars used for 250 volt direct current distribution panel, Devon Plant of the Connecticut Light & Power Company.

Anaconda Bus Bar Copper

The accurate dimensions and perfectly flat contact surfaces of Anaconda Bus Bars are the result of The American Brass Company's practice of finishing all Bus Bars hard through dies. The degree of hardness is carefully controlled so that Anaconda bars are easy to bend but will retain the required position.

Anaconda mined and refined copper assures conductivity in excess of 99.9% at 20° C. in terms of International Annealed Copper Standard.

Anaconda Bus Bars are made in any desired shape or size and are furnished in commercial bar lengths, multiples of a given length or cut to exact length.

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TURBINES

Accompanying view shows one of Four single-runner, vertical shaft, cast iron scroll-case Hydraulic Turbine Units now in successful operation in the Tugalo Plant, of Georgia Railway & Power Co.

Each turbine develops 22,000 H.P. at 171.4 Rev. under 150 ft. head and is direct-connected to a 12,500 kw. General Electric Generator.

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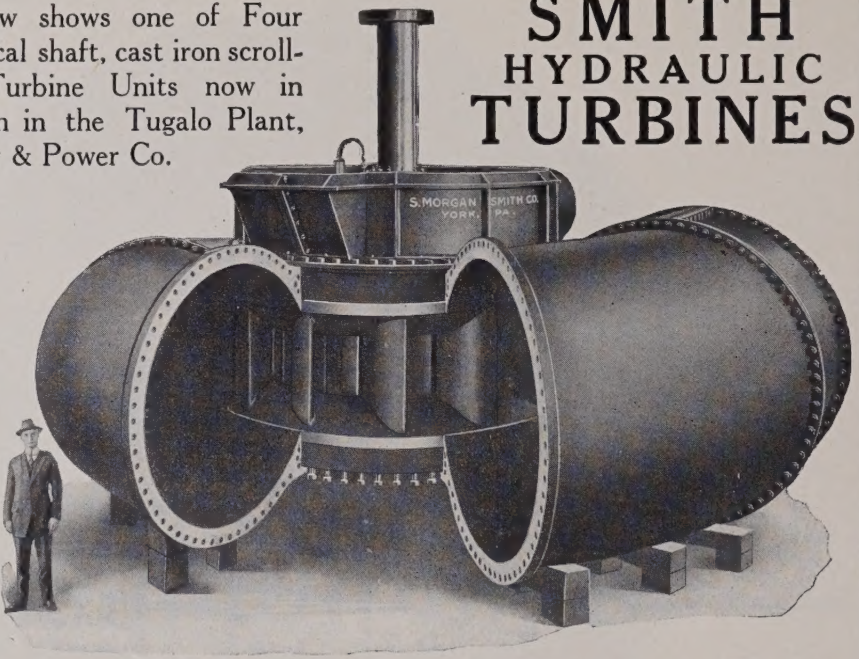

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HOFFMANN
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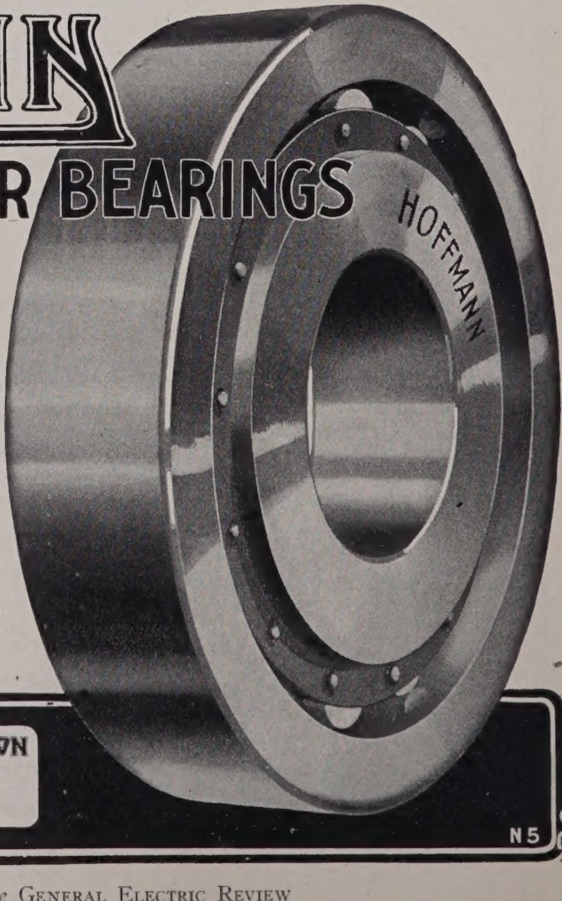

A Neglect-proof Bearing for Heavy Duty

As we've said before, the "Hoffmann" has all the load capacity and speed-ability and stand-up-ability you could ask—even where your bearing service is hardest. Here's another important feature.

It is easy so to mount a "Hoffmann" that a big reservoir of lubricant surrounds the bearing, needing renewal only at long intervals. This prevents one big cause of bearing troubles. And this mounting is dust-proof and moisture-proof.

The right "Hoffmann" Bearing, rightly mounted in your motors, will save a lot and earn a lot. Why not let our engineers work it out, with you?

NORMA-HOFFMANN BEARINGS CORPORATION
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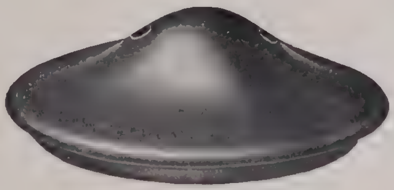
PRECISION BALL, ROLLER AND THRUST BEARINGS

N5

TYPE
9140



The New LOCKE HEWLETT

A NEW design of the Hewlett Insulator—*one which is fully equal in strength to the cemented type.*

Combining all of the inherent advantages of the Hewlett design, this new design is an improvement in every way over the original Hewlett Insulator which has enjoyed wide popularity for many years. The increased strength of the Hewlett, which, for the first time, places it on a par with cemented types, is made possible by a new method of fabrication which permits of rectangular holes for the connecting links and gives a larger bearing surface; resulting in a higher total, but lower unit stress, on the porcelain.

The contour has been changed providing for more effective washing and improving its electrical characteristics—all combining to give a more pleasing appearance.

These and many other advantages have only been made possible by the employment of dense porcelain — the same porcelain which is used in the manufacture of all Locke Insulators.

This new Hewlett is offered for any and all service where a suspension type insulator is required. General specifications and complete information, including latest data on electrical and mechanical characteristics, will be furnished upon request.

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LOCKE
PORCELAIN

LIDGERWOOD MINE HOISTS

ELECTRIC in all sizes **STEAM up to 1000 H.P.**

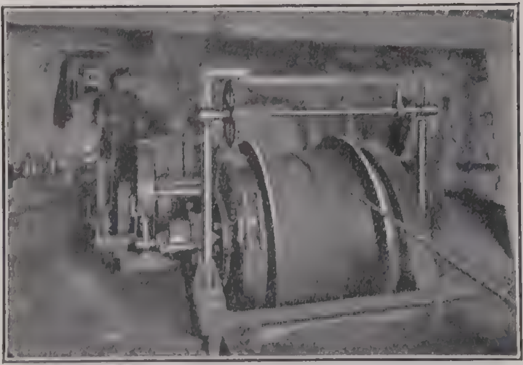

Illustration shows a slope hoist, operating an underground incline 1700 feet long. It has been in use by The Spencer Coal Co. for a number of years, and has given excellent satisfaction, both in service performed, and its wearing quality.

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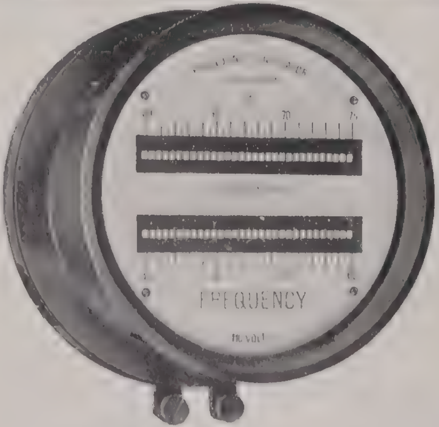

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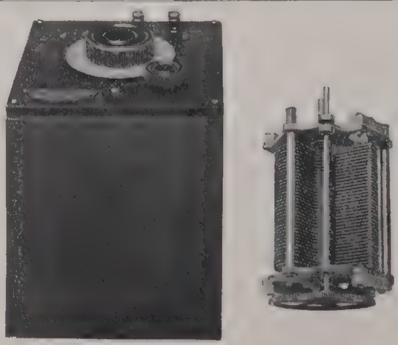

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LABORATORY CONDENSER

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Its features are low power-factor, high capacity, and permanence of calibration.

Resistance at 1000 Cycles and 1500 MMF 12 Ohms.

Type 246L, 55 MMF min., 1500 MMF max., $28.00
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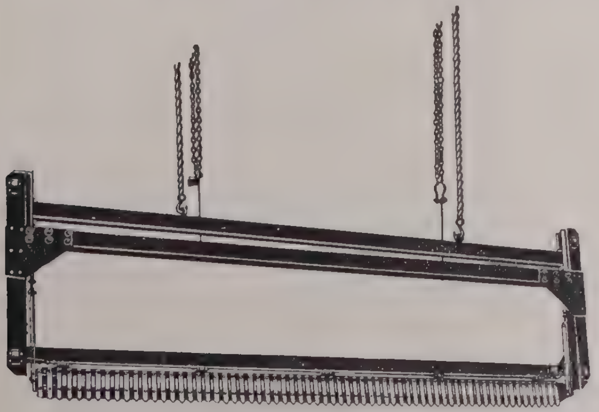
NEWPORT NEWS RACK RAKE

WILL SOLVE YOUR TRASH PROBLEMS



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Save 4 to 8% fuel.

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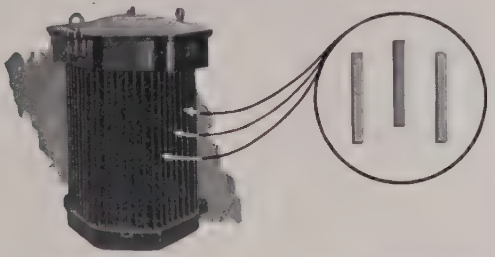

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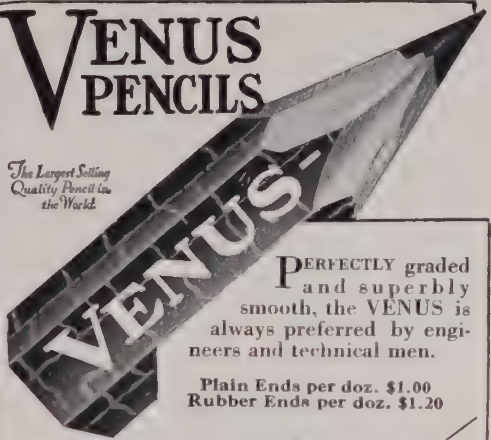

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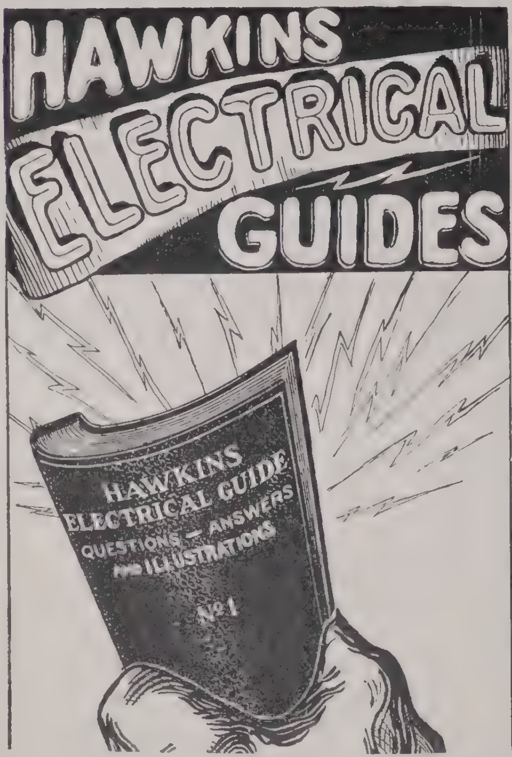
Starrett Tools



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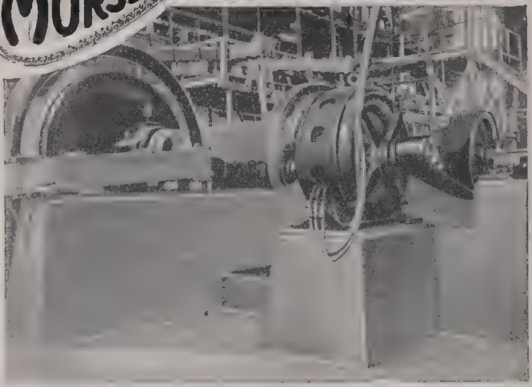

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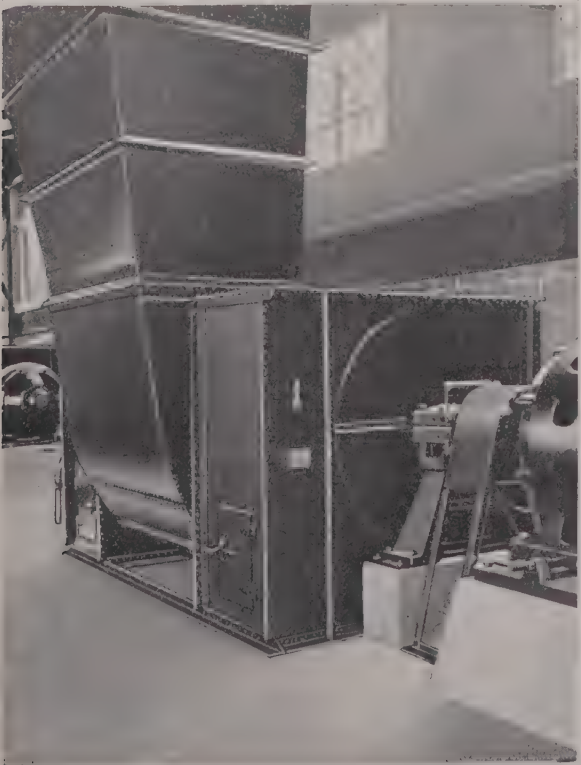

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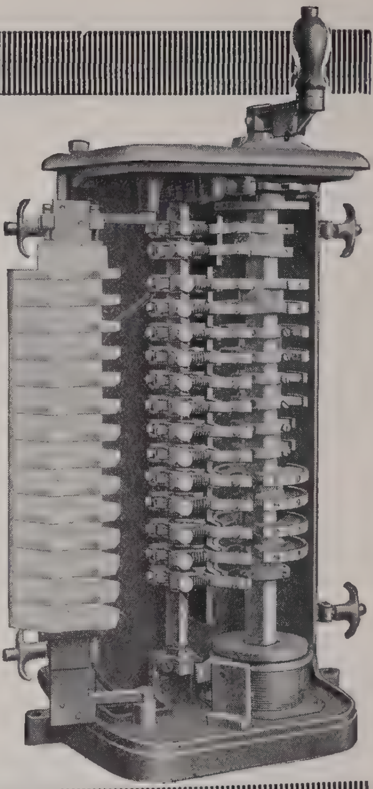

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A MONTHLY MAGAZINE FOR ENGINEERS

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A NIGHT SCENE IN CHICAGO'S NEWLY LIGHTED RESIDENTIAL DISTRICT

Ornamental Novalux lighting units, with rippled glass globe and metal canopy equipped with a 250-c-p., 6.6-amp. series Mazda lamp, installed on opposite corners at street intersections and staggered between blocks. (*See page 144*)

GENERAL ELECTRIC REVIEW

KEEPING ELECTRICITY AT WORK

When we deal today with electrical insulating materials we have available some 600 or more distinct kinds. Classified, these materials present a wide range of character as they include gases, insulating and finishing varnishes and oils, mineral insulating oils, filling and treating compounds, asphalts, enamels and paints, spirit varnishes for sticking and pasting, porcelain, quartz, refractory ceramic materials, vitreous enamels and glazes, glass, slate, molded compound insulations of wide variety, rubber, mica, asbestos, treated and untreated cloths, cotton, canvas, silk, paper of many kinds, pressboard, fibre, and wood, and still the list is far from complete. All of these serve the function of supporting and insulating electrical conductors in the many and varied forms of electrical apparatus and devices which so largely fashion our present daily life; and it is upon their ability to resist mechanical and electrical forces that the continuity of electric service is dependent.

In the design of the tiniest pocket flashlight lamp, or the highest voltage transmission line extending for miles over mountain, plain, and valley, electrical insulation occupies a most important part. The electrical designing engineer is not only confronted with the problem of arranging electrical conductors into proper configurations to produce a desired result, but he must provide for supporting them in a structure which is mechanically strong. The electrical insulation itself may act as the supporting medium, or it may act as a separator between the electrical conductors and a metallic structure in which they are embedded or to which they are connected. In either case, both mechanical and electrical forces are exerted upon the insulating material.

The underlying principles of design to resist *mechanical* forces are well founded from long experience in the design of structures. The evidence of mechanical failure is usually present and may be found upon examination of the shape and size of the faulty section and from the appearance of the fracture. The remedy is likewise usually apparent. The evidence of *electrical* failure, on the other hand, is not so susceptible to logical deductions of cause. More often than otherwise the electrical failure presents a charred mass with all evidence as to its origin obliterated. The basic elements of design to resist electrical forces must therefore be dependent upon a fundamental knowledge of the mechanism by which electrical insulation fails.

The article by Mr. F. M. Clark in this issue is a word photograph of the contributions made during the past decade to the knowledge of the mechanism of electrical failure in high-voltage gaseous dielectrics. One is awed at the volume of these contributions to the subject. From them, the principles which have already been incorporated into the design of electrical apparatus have been far reaching and are a substantial factor in the resulting efficiency and durability of the electrical apparatus of today. But as effective as these contributions have been, there are still many unanswered questions which require that there be continued investigation of the problem.

In this study the co-operation of the laboratory engineer, designing engineer, manufacturing engineer, and operating engineer is essential. The results of experiment must be translated into useful terms which can be applied to the design, manufacture, and operation of electrical apparatus. On the other hand, the problems encountered in design, manufacture, and operation must be made clear to the laboratory engineer. The ever-increasing effectiveness of this co-operation predicts a more productive and successful future.

E. S. Lee

Chicago's $2,000,000 Extension to Its Municipal Street Lighting System

By John T. Miller

Commissioner of Gas and Electricity, City of Chicago

Residential street lighting presents a problem very difficult of solution because of the many and conflicting factors to be satisfied. The following article describes an ideal solution worked out on an unusually large scale. The design of the equipment is artistic and the sides of the streets are not cluttered with posts. The daytime appearance is pleasing and the units are subordinate to the foliage in summer. High intensity is secured at street intersections, sufficient intensity at alley-ways, and adequate illumination elsewhere. The design of the system embodies simplicity, and labor-saving features were introduced to make the construction expense relatively small. The lamp circuits are subjected to low potential only; the failure of one circuit does not result in dangerous potentials nor does it leave a large area of streets unlighted; and the maintenance is reduced to a minimum by the simplicity of the designs chosen.—Editor.

The city of Chicago has grown so rapidly that the privately controlled public utilities with their broad visioned expansion policies have only with the greatest difficulty found themselves able to finance the necessary extensions to keep abreast of the city's natural developments. As the result, the public has within the past few years been awakened to the situation, and has to a rather liberal extent authorized the bond issues necessary to make such improvements possible.

In 1922, the Department of Gas and Electricity was authorized to expend $2,000,000 to extend the street lighting system.

The most pressing problem that confronted the Department in this matter was that of providing an adequate form of street illumination in the outlying residential districts which had been fully developed and long since provided with all other improvements. A preliminary survey showed that there were approximately 30 square miles of such territory that justified the installation of a modern electric street lighting system. This resolved itself into the proposition of attempting to take advantage of the latest developments in the street lighting art and to fit them in with an existing street lighting system and a personnel organization that probably has no parallel in any other city.

Chicago's municipal street lighting system prior to these latest additions consisted of 56,000 electric lamps of various types from 100 to 1000 c-p., illuminating 100 square miles of territory, and for which the city has made a capital investment of approximately $10,000,000, and spent in operation and maintenance during the past 14 years approximately $15,000,000. There are close to 400 men engaged in the care, maintenance, and operation of this system. Its connected load is 13,000 kw. and its yearly consumption approximately 52,000,000 kw-hr. Its energy cost alone during the year 1924 amounted to $448,000.

The first point of attack that was decided upon was to secure from all available sources first-hand information on the most modern type of residential street lighting that could be provided to meet Chicago's conditions. The original step in this respect was to arrange an inspection tour of other cities which was made by the writer and a group of engineers representing the City of Chicago. Visits were made to Cleveland, Detroit, Buffalo, New York City, Boston, Philadelphia, Baltimore, Washington, Milwaukee, Minneapolis, St. Paul, St. Louis and other cities. Night and day inspections and studies of the lighting effects obtained by the various designs of systems were made together with inquiries concerning the illuminating effect, investment cost, operating and maintenance cost, and discussions were held with municipal and public utility officials on present and future plans for extension. Extensive conferences were held with the illuminating engineering talent throughout the country and with illuminating engineers of the leading manufacturers of street lighting equipment and accessories. Various new devices, units, and equipment in the process of development were carefully examined.

With the general and detailed information gained from these sources, it was intended to work out a design of system that would adequately solve Chicago's residential lighting problem.

A full consideration of all the limitations, conditions, and requirements affecting the selection of a residential street lighting system for the city of Chicago necessitates careful weighing of advantages and disadvantages of units and equipment, and some compromise from a system theoretically designed to give perfect illumination. The standard city block arrangement in the residential districts to be lighted is shown in Fig. 1.

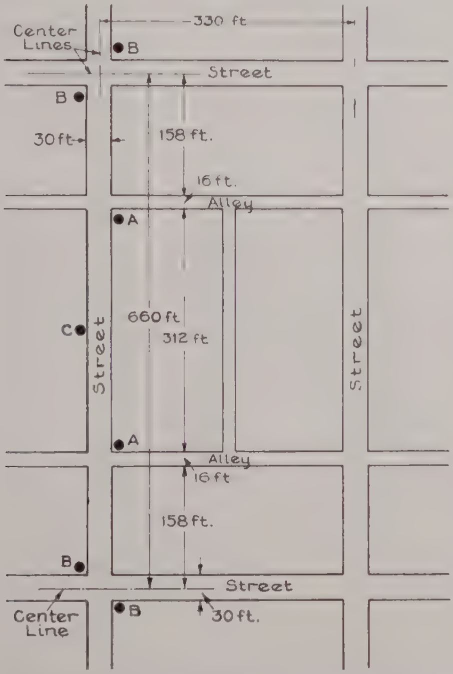


Fig. 1. Layout of Residential Block, Showing Location of Lamp Units at *A*, *B* and *C*

Chicago blocks are extensively provided with alleys which is not the case in the blocks of most other cities. These alleys, while forming a great convenience for the delivery of goods, coal, hauling away garbage and ashes, and for entrance to private garages, afford good lurking places in which to commit the crime prevalent in large cities. It is therefore imperative to light their entrances to the street by placing lamp units at the alley intersections, as indicated by the designations *A* in Fig. 1. These units will illuminate the alleys, and the placement of the units is arbitrary to give the greatest protection to the pedestrian walking along the sidewalk of the street. At the intersections of streets the necessity of providing a higher intensity of illumination to minimize automobile collisions and danger to pedestrians determines the placement of two units, indicated as *B* in Fig. 1. An additional advantage is afforded by the use of two units for, with the improbability of two lamps burning out simultaneously, there is small likelihood of the street intersection being placed in darkness as would be the case if only one unit were used. By placing a third unit marked *C* in Fig. 1, a system comprising five lamps to the block is obtained giving maximum effect at the street intersections, light protection at the alleys, and lesser but sufficient distribution in the other portions of the block. Believing that a system embracing these fundamentals was the correct solution to the residential requirements, experimental test installations were made to check the conclusions and determine the selection of other elements of the system.

Several installations of a block each were made using 250-c-p. 6.6-amp. series-burning lamps, spaced in the manner as shown in Fig. 1. Among these installations were included:

(a) Novalux Ornamental Lantern Units, Form 23-A, with 8½-in. Holophane Prismatic Dome Refractors. One block of these units was mounted on Union Metal No. 1298 lamp standards, and a second block on concrete lamp standards of the "Chicago Beautiful" type. The mounting heights were 12 ft. 6 in.

(b) Octagonal Junior Reflectolux Lanterns. One block was installed with reflectors only and mounted on cast-iron lamp standards, and one block with Bilux refractors mounted on concrete lamp standards having a precast foundation. The mounting height was 12 ft. 6 in. to the light source.

(c) Holophane Refractors No. 4937 having a mounting height of 12 ft. 6 in. to the light source.

(d) Installations of rippled glass globes of the Novalux design, special ball globes of the "cased" glass construction, and other adaptations and modifications.

The experimental installations were completed for the most part early in December, 1923, and were placed in continuous operation throughout the winter and spring. Comparative photometric tests were made under various weather conditions.

Because sections of the system to be chosen for the extensions would be interspersed with sections of an already large existing system, much time and study was given to the careful consideration of maintenance and operation details to permit economic absorption into the existing system of substation equipment, lamps, globes, cables and transformers. The method of cleaning globes, renewing and replacing lamps, patrolling the system for outages, already highly organized, should be capable of economic application to the new system. Detail equipment such as sockets, receptacles, and other accessory fittings and appliances should be standard with the existing system if possible.

All improvements resulting in a possible saving of construction labor and labor of maintenance and operation should be incorporated. Any improvements made or selected should be capable of application to a rehabilitation of the already existing system without prohibitive expense. In conclusion, the new system chosen should represent the latest economic development in the art; provide illumination sufficient for the purpose intended; show a marked saving in construction, maintenance, and operation over previous systems; meet any new conditions that have arisen; and be so designed as to permit incorporating future improvements without nullifying the original investment.

The lamp post shown in Fig. 2 was adopted as the standard for use in residential districts. The post was designed by the Department of Gas and Electricity and is of concrete construction. It is 10 ft. 8 in. high and 18 in. wide at the base. Several distinctive features are embodied in its design and construction. To form the raceway for the circuit cables, a two-inch iron pipe is cast longitudinally in the center of the concrete post. The bottom end of the pipe is screwed into a three-armed malleable-iron spider, the face of which is flush with the bottom of the concrete post, and the arms project beyond the edge of the base of the post. The post is bolted to its foundation through holes at the ends of the arms of the spider.

Fig. 3 shows the spider in the base of the post. At the top of the post, the two-inch iron pipe projects one inch above the concrete and is threaded to receive the globe holder. In Fig. 2 the globe holder has been screwed into position. Previous designs of concrete posts have been restricted to rounded surfaces of large curvature because of the manufacturing difficulties experienced in casting concrete. However, by the use of properly designed, accurately machined, cast-iron moulds it has been possible to produce a fluted base and other surfaces that give an artistic concrete post of pleasing and harmonious form. The use of a concrete post eliminates the painting item from the maintenance cost.

To support each lamp post, a concrete foundation 28 in. in diameter and 42 in. deep is poured, using only the earth wall as a form. At the time of pouring, a two-inch iron-pipe bend and three foundation bolts are held in position by a template and cast into the foundation. The foundation top is placed two inches below the grade of the curb and the center of the foundation is placed 36 in. from the inside edge of the curb, to reduce to a minimum the possibility of having the lamp posts struck by automobiles and trucks.

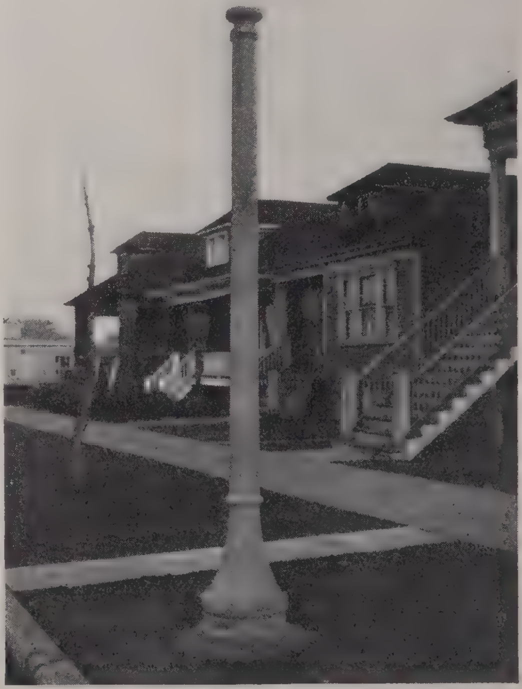


Fig. 2. Concrete Lamp Post for Use in Residential Districts

Fig. 4 shows the completed foundation which is allowed a drying period of not less than 20 days before the lamp post is erected upon it. Fig. 5 shows a lamp post bolted to its foundation; and Fig. 6 shows the cement grouting applied to cover the exposed bolts and ends of the spider.

This method of construction has a distinct advantage over a post with precast and attached foundation in that it permits the foundation work to be done without delay while the posts are in the process of manufacture, and from the maintenance standpoint permits the replacement of a damaged

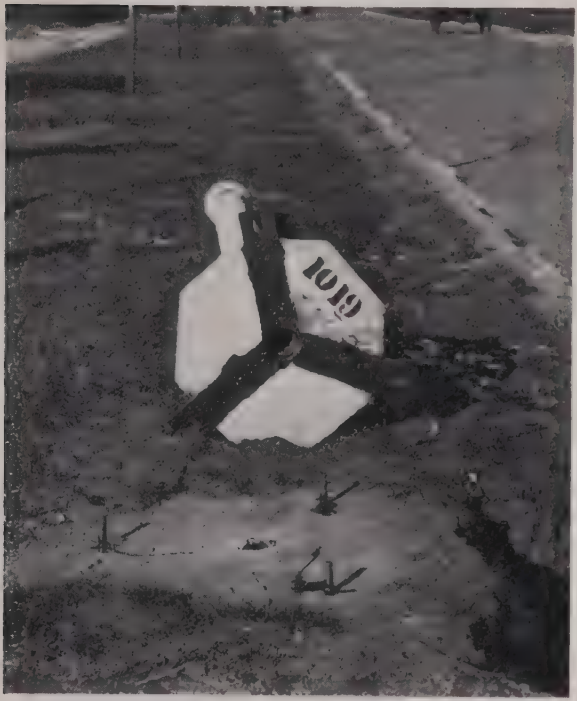


Fig. 3. Malleable-iron Spider Cast in Base for Bolting the Post to Its Foundation

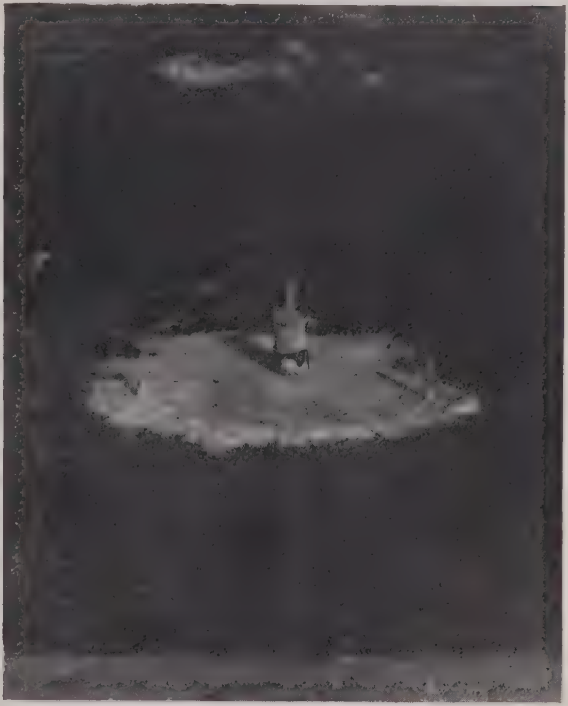


Fig. 4. Completed Lamp Post Foundation, Showing End of Iron-pipe Bend and Foundation Bolts

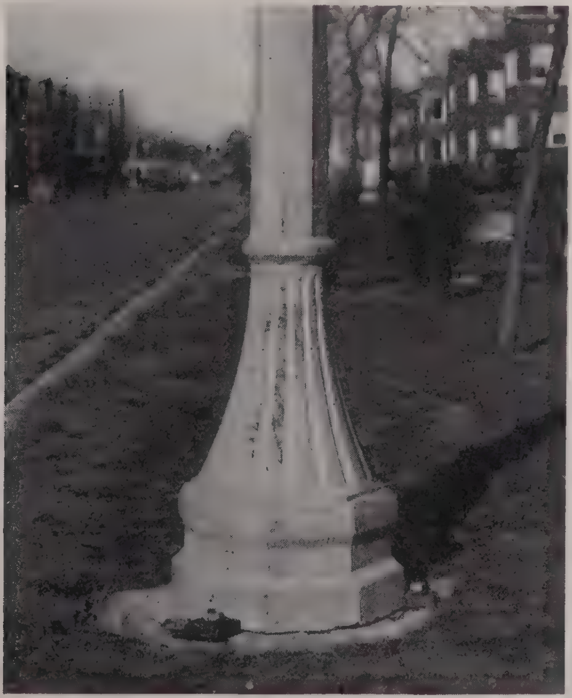


Fig. 5. Lamp Post Bolted to Its Foundation

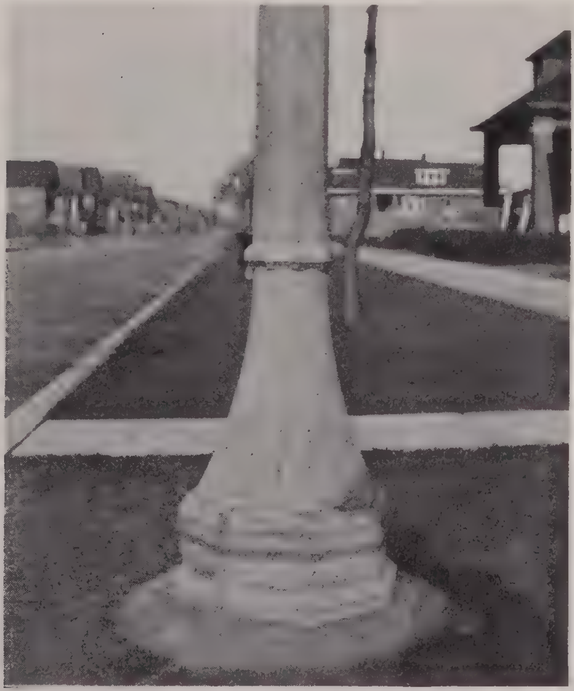


Fig. 6. Completed Lamp Post Base with Bolts and Ends of Spider Concealed

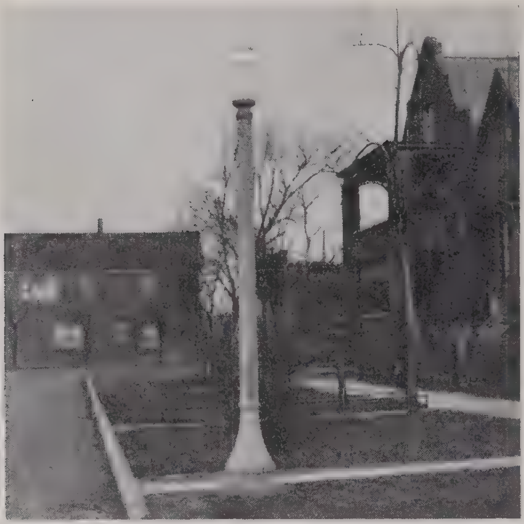


Fig. 7. Day View of One of the New Completely Assembled and Installed Residential Lighting Units

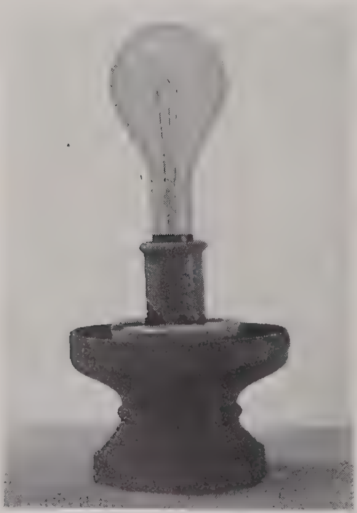


Fig. 8. Assembly of 250-c-p. Series-burning 6.6-amp. Mazda Lamp, Socket, Receptacle, and Base Casting

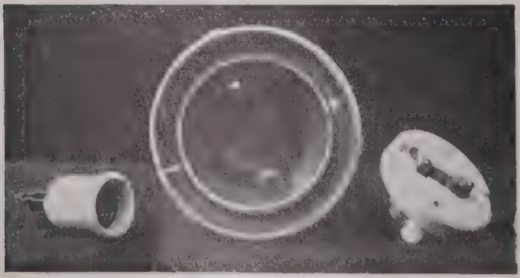


Fig. 9. Socket, Receptacle, and Base Casting Shown Assembled in Fig. 8

post under all weather conditions without disturbing the foundation, and therefore promotes speed of restoration with minimum cost.

The post-top lamp fixture, housing a 250-c-p. series-burning 6.6-amp. Mazda lamp, is shown in Fig. 7 completely assembled and mounted on the post. The lower part is an aluminum casting of natural finish and is screwed on the extension of the two-inch pipe at the top of the post. Fig. 8 shows the lamp, socket, receptacle, and casting assembled; and Fig. 9 shows the separate casting, socket, and receptacle casting. Fig. 10 is a photograph of the completely assembled post top. The globe is of rippled glass and is a departure from the standard Novalux type in that the bottom of the globe has a greater curvature, effecting a greater distribution of light immediately adjacent to the base of the post. The top canopy is an aluminum spinning of natural finish and designed to support possible future improvements in the form of reflectors or refractors that may become economically available. The adoption of this type of fixture will permit the renewing of lamps and testing for trouble with the simple removal of the canopy, and probably will

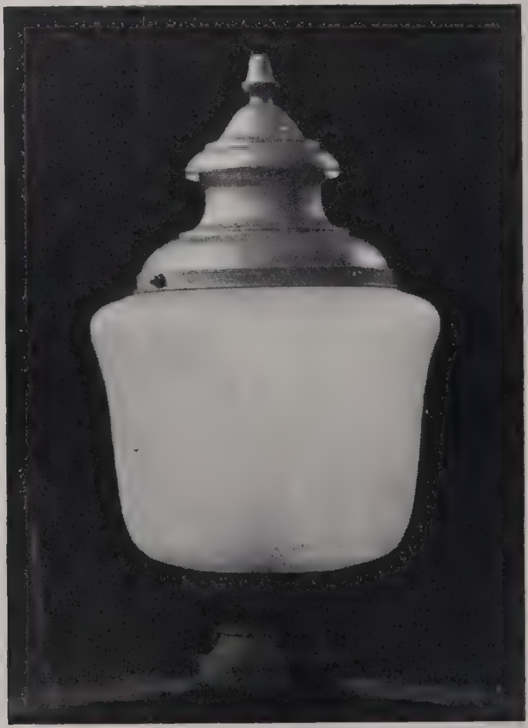
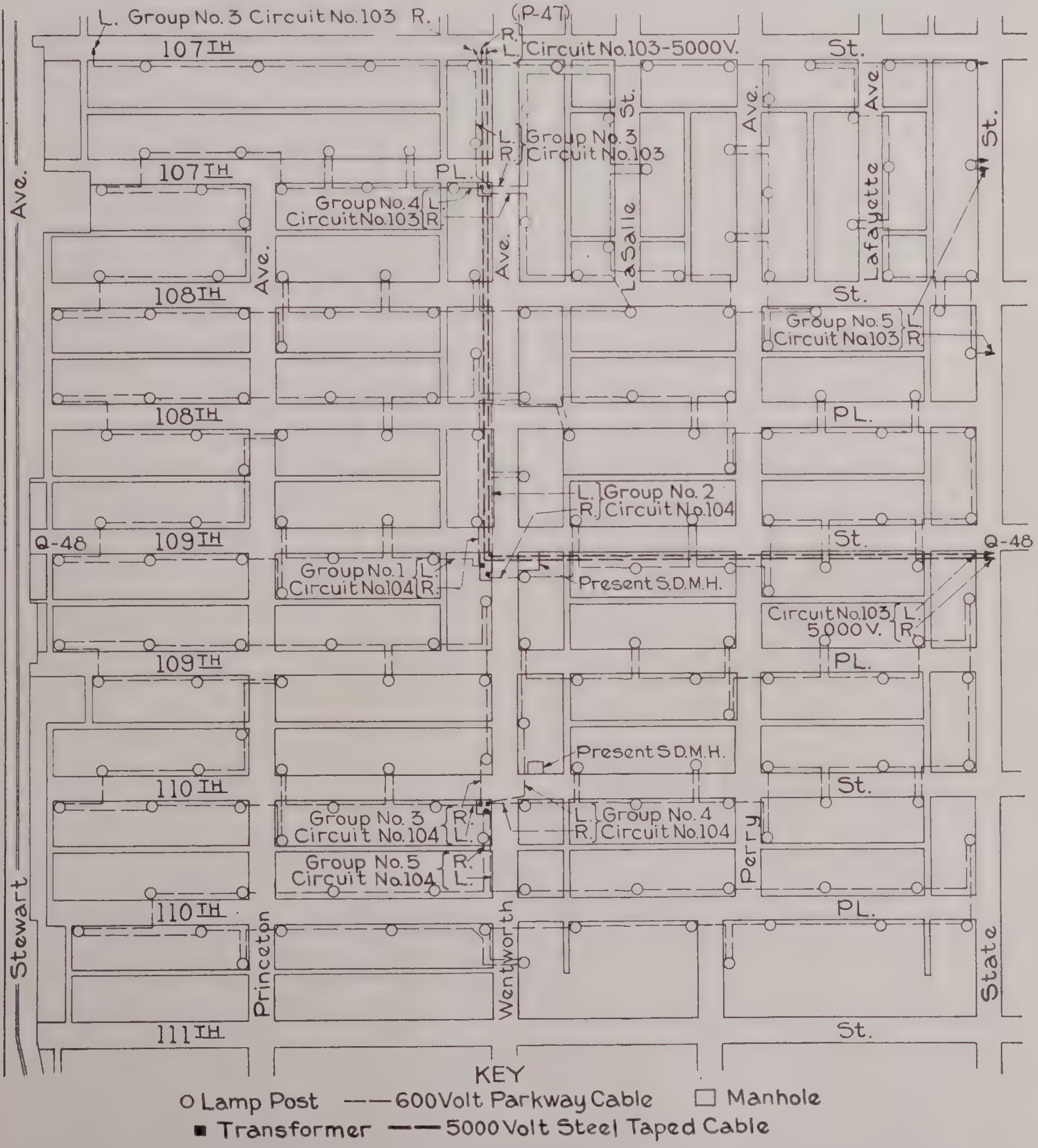


Fig. 10. Completely Assembled Post-top Lighting Unit

be a factor in decreasing the breakage of glassware since the globes will not need to be disturbed.

Approximately 25 lamps are connected together by 600-volt, No. 8 B.&S. gauge, solid-copper, single-conductor, lead-covered, jute-covered cable laid in trenches dug in the parkways adjacent to the curb, and passing through two-inch iron-pipe laterals installed beneath the surfaces of the streets, alleys, and sidewalks, and then passing through and up the lamp posts to form a continuous series circuit known as the secondary or "group" lamp circuit. The insulation on the


L. Group No. 3 Circuit No. 103 R.
(P-47)
R.
L. Circuit No. 103-5000 V.
107TH
St.
107TH
PL.
L. R. Group No. 3 Circuit No. 103
Group No. 4 Circuit No. 103 L. R.
Ave.
Ave.
Ave.
St.
LaSalle
Ave.
Ave.
Lafayette
St.
108TH
St.
Group No. 5 Circuit No. 103 L. R.
108TH
PL.
L. R. Group No. 2 Circuit No. 104
Q-48
109TH
St.
Q-48
Group No. 1 Circuit No. 104 L. R.
Present S.D.M.H.
Circuit No. 103 5000 V. L. R.
109TH
PL.
Present S.D.M.H.
110TH
St.
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L. R. Group No. 4 Circuit No. 104
Perry
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110TH
PL.
Stewart
Princeton
Wentworth
State
111TH
St.
KEY
○ Lamp Post
——— 600 Volt Parkway Cable
☐ Manhole
■ Transformer
——— 5000 Volt Steel Taped Cable

Fig. 11. Working Drawing of a Typical Section of the Parkway Cable Installation, Showing Layout of the Lamp Circuits

cable is a $\frac{3}{64}$-in. thick wall of 30 per cent Para rubber, taped and encased in a lead sheath having a $\frac{3}{16}$-in. thick wall of commercially pure lead. The lead-covered cable is run through a hot asphaltum compound at the factory, served with a layer of 70-lb. jute, and then treated with soapstone or talc to prevent sticking. The trenches are dug 24 in. deep and of sufficient width to contain the cable or cables. Fig. 11 is a working drawing of a typical section of the parkway cable installation, showing various group lamp circuits.

Each group lamp circuit terminates at the secondary winding of a 4.2-kv-a. series transformer. These transformers are of a one-to-one current ratio, having 6.6-amp. windings. Each transformer is equipped with a secondary-short-circuiting device which operates through the breakdown of a film at 800 volts in case of an open secondary circuit other than individual lamp failure. Open circuits due to individual lamp failures are closed by the puncturing of the film in the lamp socket. One to four transformers are placed on individual concrete piers in manholes which are located centrally with reference to the connected group lamp circuits. The large rectangles in Fig. 11 indicate the manholes and the smaller solid rectangles within them indicate the transformers. The primary windings of seven transformers are connected together by 5000-volt, No. 8 B.&S. gauge, solid-copper, single-conductor, lead-covered, steel-taped, jute-covered cable laid in trenches adjacent to the curb and passing through two-inch iron-pipe laterals under the streets, alleys, and sidewalks to form a continuous 5000-volt primary series circuit, as shown by heavy lines in Fig. 11. The insulation on this cable is a $\frac{5}{32}$-in. wall of 30 per cent Para rubber; a $\frac{1}{16}$-in. wall lead sheath of commercially pure lead; a $\frac{5}{16}$-in. wall of 100-lb. jute yarn; two layers of steel tape of 30-mil steel; two layers of 100-lb. jute treated with asphaltum compound and then covered with soapstone or talc to prevent sticking. Four 5000-volt primary circuits terminating at a distribution center are connected to an eight-conductor lead-covered cable passing through underground conduits to the substation. Each substation receives 12,000-volt, 3-phase, 60-cycle energy. The transformer banks, each bank consisting of three single-phase, 250-kv-a. transformers, connected 12,000-volt, 3-phase, delta on the primary side and 5050-volt, 3-phase, 4-wire star on the secondary side, provide the energy for the street lighting circuits. Each street lighting circuit is single-phase, with 5050 volts between phase and neutral, and each circuit substation equipment consists of an oil switch with overload and no-voltage release, ammeter, disconnecting switches and impedance regulator adjusted for a constant current of 6.6 amp.

The work of construction and installation is being done both by contract and by the city of Chicago's day labor forces. After receiving several bids from various contractors on the different portions of the work, a decision was made to install 2442 units by contract in the westerly part of the city and the remaining 4108 units in the north and south parts of the city by the city of Chicago's own day labor forces.

The work was divided into its component parts, specialized gangs organized, and equipment arranged to produce the maximum speed of installation consistent with economy.

Work was started on July 29, 1924, and on December 31, a period of five months, 90 per cent of the construction work was completed; 1824 units were in service on December 31 and the remaining 4726 units were scheduled for service before March 1, 1925.

In conclusion, the author wishes to extend to those associated with him in this work credit for their valuable assistance: Mr. J. C. Hail, Deputy Commissioner of Gas and Electricity; Mr. F. H. Snyder, Operating Engineer of the City Electrical Department; Capt. F. H. Cenfield and Mr. C. A. Reeder of the City's Council Technical Staff; together with the various other engineers and manufacturers' representatives who co-operated diligently in making this extension to Chicago's street lighting system entirely fulfil its requirements.

Observations of the Total Solar Eclipse Made by the Electric Companies in and Around New York City, January 24, 1925

For the first time in the history of the United States her largest city, New York, was this winter visited by a total eclipse of the sun. While it is natural that every citizen should have made an effort to observe this great phenomenon for himself, the data of real value came from organized research that was conducted at the same time. One of the achievements, noteworthy because of being the first of its kind, was the making of several types of observations by members of the local electric service companies, following the inspiration of John W. Lieb, Vice-President of the New York Edison Co. One study was made to determine the location of the shadow's edge and another the effect of the eclipse on the lighting and power loads. From data furnished by the companies taking part, we are here presenting a description of how the investigations were conducted and a record of the results obtained. In addition to the worth of the information thus secured, the work affords an excellent example of the co-operation which public utility companies offer in matters of general public interest even though productive of no revenue to themselves.—EDITOR.

The long and narrow strip on the earth's surface within which the total eclipse of the sun was visible last January fell partially across the territory where electric light and power service is rendered by the New York Edison–United Companies, and allied electric utilities.

While the astronomical and other scientific features of the eclipse were being investigated and recorded under the auspices of authorities having specialized knowledge in those several fields, it was felt that there would also be interest in some of the industrial and social aspects of the extraordinary phenomenon as affecting the light and power services in the vicinity of New York City. To gain such information, it was decided that the allied electric utility companies should be thoroughly organized into committees operating in the various zones for the definite purpose of obtaining all practicable data as to the effect of the eclipse on the load carried by the several stations and substations, the exact determination of the zone of totality, photometric determinations of light intensities during the several phases of the eclipse, the provisions necessary for adequate street and highway lighting, etc.

The co-operating companies in this investigation were the:

Bronx Gas & Electric Co.
New York & Queens Electric Light & Power Co.
Northern Westchester Lighting Co.
Peekskill Railway & Lighting Co.
New York Edison Co.
United Electric Light & Power Co.
Yonkers Electric Light & Power Co.
Westchester Lighting Co.

Determining the Limit of Totality

The New York Edison Company assigned its Test Department to co-operate with the Astronomical Society in an effort to establish as exactly as possible the southern edge of the shadow of totality as it crossed Manhattan Island in New York City. The location of the totality limit was, from calculation, expected to lie across the Island at about 110th Street and a variance of a mile either way was felt to be not improbable.

Two independent methods were proposed for observing and checking the edge of the shadow, as follows:

(a) The placing of a line of observers at right angles to the edge of the shadow, so stationed as to look out over an expanse on which they might see the oncoming shadow and report whether the line of division between shadow and light lay to the right or to the left of their positions.

(b) The placing of another series of observers on a line at right angles to the edge of the shadow, equipped with screens for directly observing the sun. The members of this group could be expected to report whether they observed a total or only a partial eclipse.

Both methods were used to serve as checks on each other. Riverside Drive and West End Avenue (along the Hudson River) were selected as the most favorable line in which to station the majority of the observers. Accordingly, with the permission of the house-owners, 70 observation groups were stationed on roofs between 72nd and 135th Streets. Besides these stations paralleling the Hudson, three others were selected off the eastern edge of the Island. Two of these were on the connecting bridge of the New York, New Haven & Hartford Railroad, and the other was on the property of the Astoria Light, Heat & Power Co. The exact location of all these stations is shown in Fig. 1.

In all, 149 men were used for the survey. The group was organized around a nucleus of technically trained and experienced testers from the Test Department of the New York

Edison Company. The men were carefully coached and instructed in their duties and assigned in squads of two or three to specific locations.

A watch, checked to standard time by comparison with government signals from Arlington, was assigned to each squad. Each watch was standardized on the evening prior to the eclipse and again after the observations on Saturday morning.

The 74 "a" observers who were instructed to look for the shadow on the surface of the earth reported (with one exception) their inability to see the oncoming umbra, or to see a definite line of light and dark on the river or the ground. The single exception was the observer located at 89th Street, who was peculiarly placed with respect to the Soldiers' and Sailors' monument on Riverside Drive nearby. He reported that he could see the edge of the shadow definitely apparent to the north of the monument and that the south side of the monument was lighter and lay in the area of partial eclipse. It is interesting to note that from the observations of the other 148 observers this man's station lay seven blocks south of the subsequently determined line of totality.

The reports of the 75 "b" observers who looked directly at the sun to report total or partial covering were positive and consistent. When these reports were spotted on the map, it was at once apparent that a sharp and definite line of demarkation was established at 96th Street and Riverside Drive. The observer north of 96th Street saw the sun completely covered by the moon and his report was consistently supported by the 40 other observers to the north. The observer south of 96th Street saw the sun not completely covered and his report was consistently supported by the observers south of

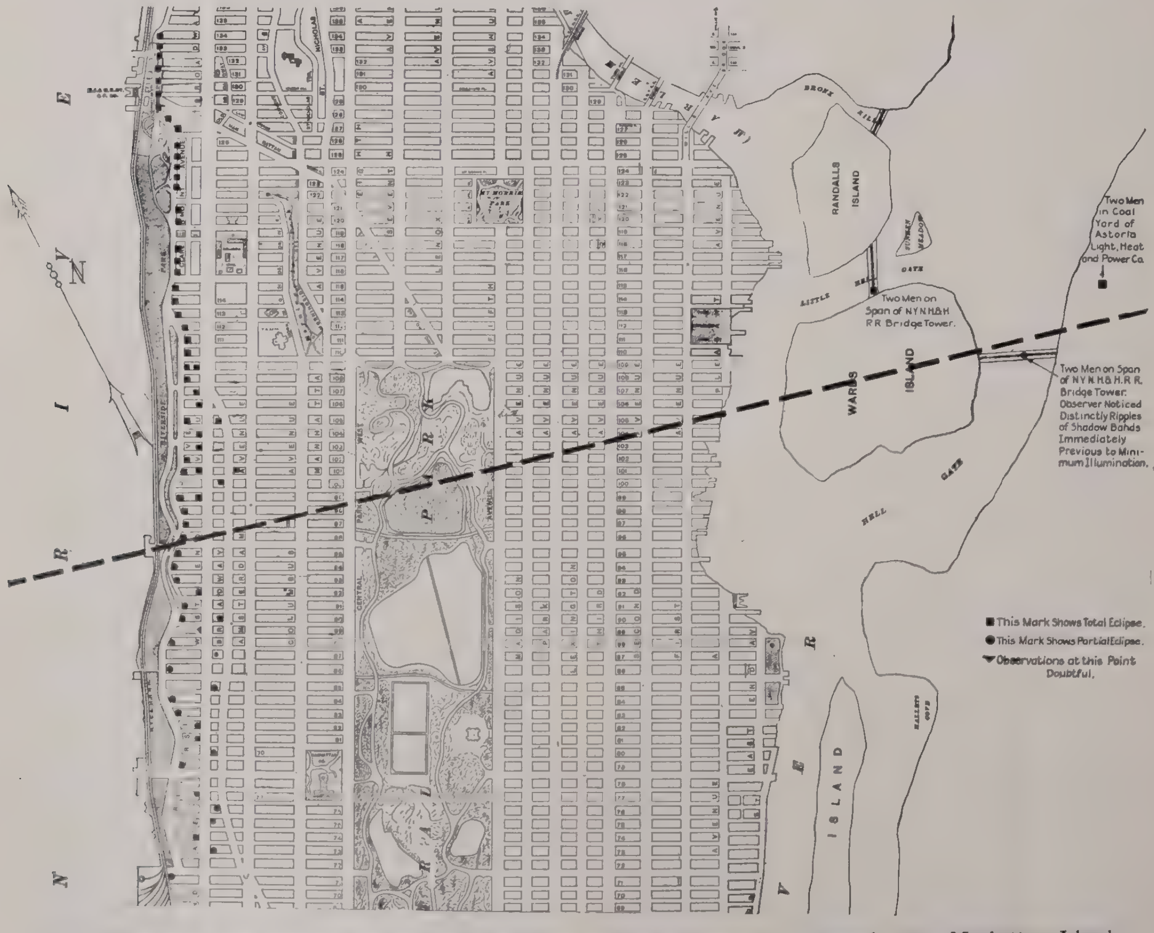
N
RANDALLS ISLAND
WARDS ISLAND
SUNKEN MEADOW
LITTLE HELL GATE
HELL GATE
BRONX KIL
HALLETS COVE
CENTRAL PARK
RIVERSIDE
Two Men in Coal Yard of Astoria Light, Heat and Power Co.
Two Men on Span of N Y N H & H RR Bridge Tower.
Two Men on Span of N Y N H & H R R Bridge Tower. Observer Noticed Distinctly Ripples of Shadow Bands Immediately Previous to Minimum Illumination.
■ This Mark Shows Total Eclipse.
● This Mark Shows Partial Eclipse.
▼ Observations at this Point Doubtful.

Fig. 1. The heavy dash line marks the southern edge of the total eclipse shadow as it passed across Manhattan Island. Its location was determined from an elaborate survey in which many observers took part. They were stationed at the points indicated, and the legend at the lower right indicates the nature of their reports

him, with the exception of the 89th Street man. From these results it may be definitely concluded that the line of totality fell between No. 230 and 240 Riverside Drive, thus establishing the position of the moon's shadow within the 225 ft. separating the observers on these buildings.

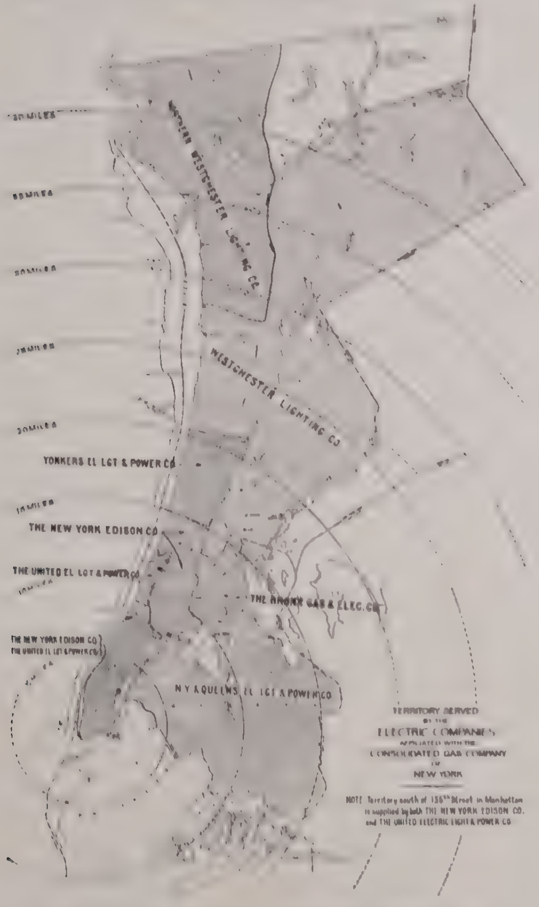
NORTHERN WESTCHESTER LIGHTING CO.
WESTCHESTER LIGHTING CO
YONKERS EL LGT & POWER CO
THE NEW YORK EDISON CO
THE UNITED EL LGT & POWER CO
THE BRONX GAS & ELEC. CO
THE NEW YORK EDISON CO
THE UNITED EL LGT & POWER CO
N Y & QUEENS EL LGT & POWER CO
TERRITORY SERVED BY THE ELECTRIC COMPANIES AFFILIATED WITH THE CONSOLIDATED GAS COMPANY OF NEW YORK
NOTE Territory south of 135th Street in Manhattan is supplied by both THE NEW YORK EDISON CO. and THE UNITED ELECTRIC LIGHT & POWER CO

Fig. 2. Key Map to the Territories Covered by the Electric Companies Whose Load Diagrams Are Shown in Figs. 3 to 13

Those in the three groups located on the eastern margin of Manhattan Island furnished data by which the edge of the shadow was determined to lie within a space of 750 ft. By joining these two points on the map the observed line of totality was found to be parallel to that predicted by calculations, thereby constituting an excellent check on the observations.

Aside from the establishment of the line itself across the Island, which was one purpose of the investigation, three points of interest may be mentioned:

(1) The failure to see the coming of the shadow or to see it as it lay on the surface of the earth.(1) It is possible that the river-surface conditions of haze, the city conditions of smoke, steam, etc., and the relatively limited elevation of the observers above the surface of the earth may have been responsible for this failure.

(2) The enormous contrast between even a minute sliver of the sun's disk and the light from the corona, which permitted positive and supported reports from observers located 225 ft. apart, one reporting total and the other only partial eclipse.

(3) The very close check between observed and computed results. A tribute is due to the astronomers who were able to predict the position of totality within a few hundred feet. This is made evident when it is considered that the shadow was cast by an object 230,000 miles away, interrupting light coming 93,000,000 miles and falling upon a surface moving through space at the rate of 18 miles per second.

Station Load Measurements During the Eclipse

The determining of the special load conditions resulting from the eclipse darkness was carried out by a group of men stationed at the various generating plants of the allied companies. In order that all readings might be properly co-ordinated, a special set of signals was adopted, which was sent out over the emergency signal system to all stations on this system, and was relayed to outlying stations over the load dispatcher's private telephone wires. These private wires were consequently rendered unavailable for their usual purposes and operators were instructed to use public telephone service for emergency communication.

Readings of total station load were taken during the morning at the following intervals:

Before 8:00 and after 10:30 a.m. .	30 minutes
From 8:00 to 9:00 a.m. and from 9:25 to 10:30 a.m.	5 minutes
From 9:00 to 9:25 a.m.	½ minute

From these readings were plotted the charts shown on the following four pages. In general the curves indicate an increase in load with oncoming darkness, the peak being reached five to ten minutes after totality. This is an interesting fact, for it demonstrates that soon after the corona disappeared people tired of the eclipse and returned to their houses, making the load much heavier than for the equally dark period just before totality.

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(1) In making this statement the report of the observer at 80th Street is excluded as being of doubtful accuracy.

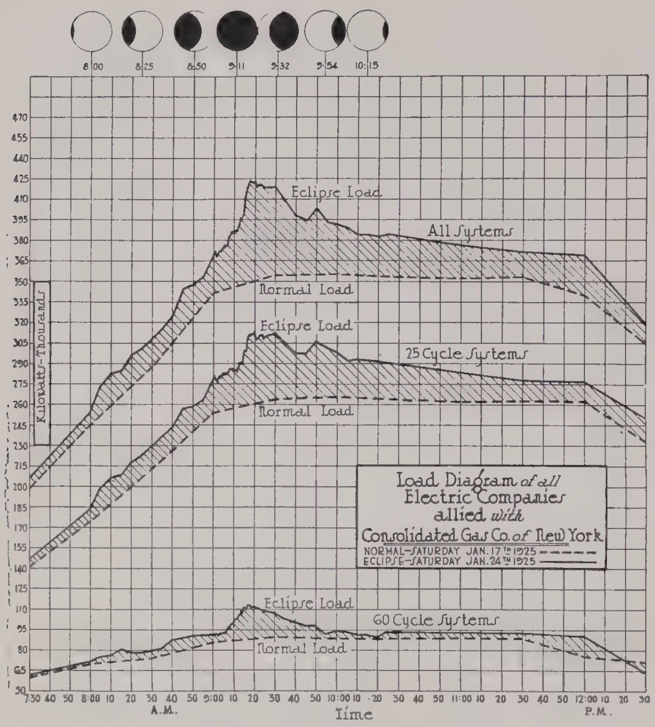

Fig. 3. Combined Load Diagrams of All the Companies Taking Part in the Investigation

The succession of blackened disks at the top of this diagram, and those following, indicate the percentage of the surface of the sun visible at the times named.

(**Fig. 3.**) The 25-cycle load supplies Manhattan south of 135th Street, while the 60-cycle load includes Manhattan above 135th, Bronx, Yonkers, Queens and Westchester County. Both loads were near normal until about 9:00, with peaks at 9:18. The 60-cycle load returned to normal 50 minutes after the peak load but the 25-cycle load was high until noon.

The 60-cycle load is mostly residential, and the curve shows a demand in accordance with the need for illumination, with a slight lag on the decline from the peak load. The 25-cycle load is largely commercial, and this is shown in the much greater lag in the decline from the peak load. Evidently in many offices and stores where the lights were turned on during the period of darkness, they were not turned off for the rest of the morning. The minor peak in the 25-cycle load at 9:50 was due to the opening at that time of many stores which had permitted their employees to view the eclipse. The total eclipse load was 27.3 per cent over normal at the peak.

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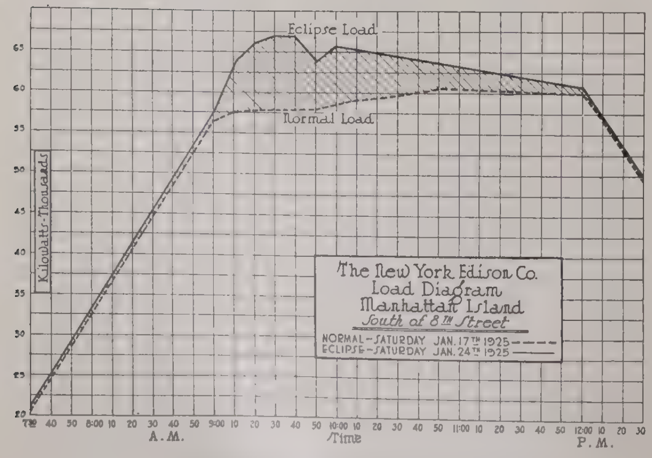

Fig. 4. Manhattan Island South of 8th Street as Served by the New York Edison Co.

(**Fig. 4.**) The increase in the load on Manhattan Island, south of 8th Street, on the day of the eclipse corresponded to that of the preceding Saturday up to 9:00 o'clock, from which point the load continued on a sharp increase to a maximum of 67,000 kilowatts, as compared with 57,500 kilowatts on the preceding Saturday, January 17th.

The load began to fall off sharply at 9:40 after totality due to the turning off of lights by those who were in offices and industrial establishments. This decrease was checked and a sharp increase took place from 9:50 to 10:00 o'clock, due possibly to the turning on of lights as on a normal business day by those who returned to their offices after being outside observing the eclipse. The peak load increase over normal was 16.5 per cent.

(**Fig. 5.**) The increase in the load on Manhattan Island between 8th and 59th Streets on the day of the eclipse was similar to that of the preceding Saturday, up to 9:00 o'clock, from which point the load continued to increase to a peak of 121,000 kilowatts at 9:40. In this district the increase continued to a maximum of 124,000 kilowatts as compared with 103,000 kilowatts on the preceding Saturday morning. This load held for some time, falling off only slightly up to 12:00 o'clock.

The failure to return to normal soon after the eclipse is the usual condition following any reduction in normal daylight, as people turn on lights and then neglect to turn them off. This is particularly true in offices and industrial establishments. Increase, 20.9 per cent.

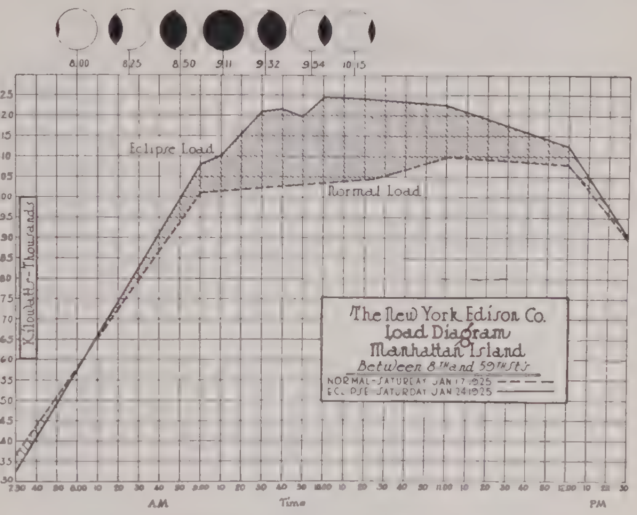

Fig. 5. Manhattan Island Between 8th and 59th Streets as Served by the New York Edison Co.

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(**Fig. 6.**) Manhattan Island between 59th and 135th Streets is almost entirely residential. The lighting load increased steadily from 8:00 o'clock up to the maximum peak of 48,500 kilowatts, at 9:20, as compared with 35,500 kilowatts on the preceding Saturday. This fell off very rapidly, returning to normal at about 11:30 o'clock. The eclipse peak was 36.6 per cent above normal.

The reduction in the load following the peak at 9:20 was more rapid in this part of Manhattan than in the other parts, due probably to the habit of turning off unnecessary lights in residences more quickly than in offices and industrial establishments.

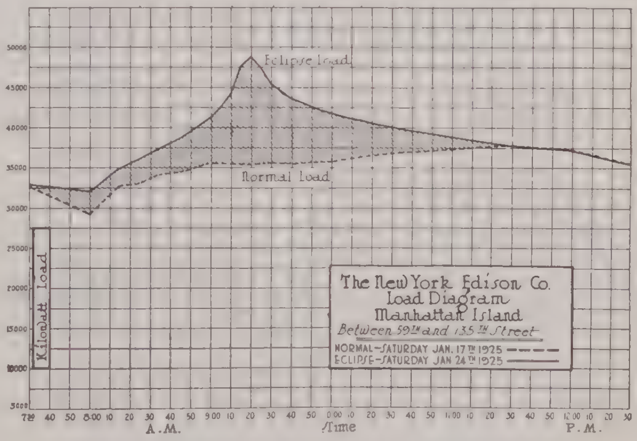

Fig. 6. Manhattan Island Between 59th and 135th Streets as Served by the New York Edison Co.

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(**Fig. 7.**) The load in the Bronx District did not come up to the normal load of the preceding Saturday until shortly before the total eclipse when there was a sudden jump, due to the darkness. Soon after totality the load fell to below normal where it remained for the remainder of the morning.

This was probably due to the fact that many of the smaller industries did not carry on their business as usual during that day. Nevertheless, the peak at 9:20 was 27.3 per cent higher than normal.

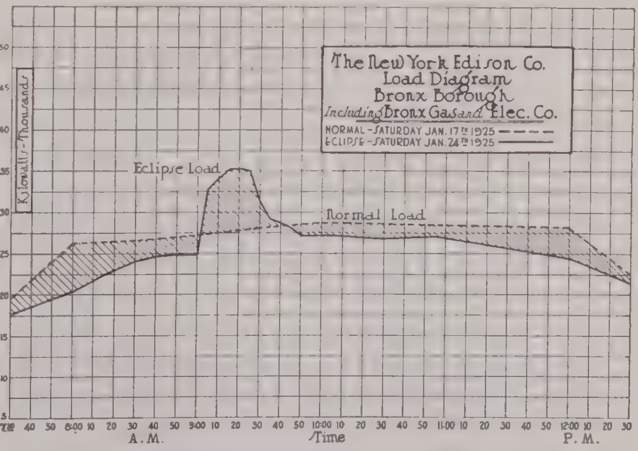

Fig. 7. Bronx Borough as Served by the New York Edison Co. and the Bronx Gas & Electric Co.

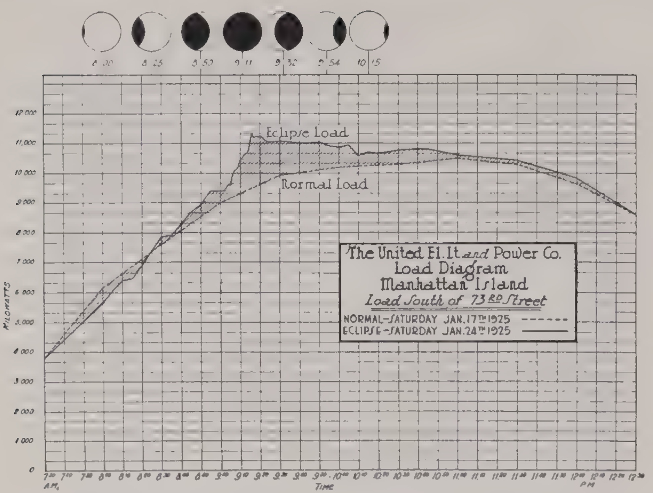

Fig. 8. Manhattan Island South of 73rd Street as Served by the United Electric Light & Power Co.

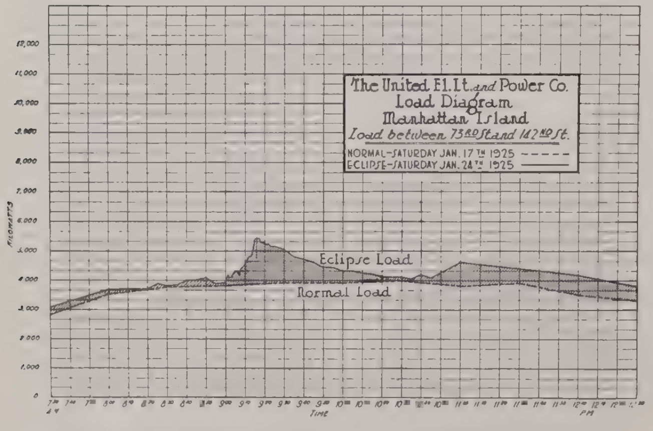

Fig. 9. Manhattan Between 73rd and 142nd Streets as Served by the United Electric Light & Power Co.

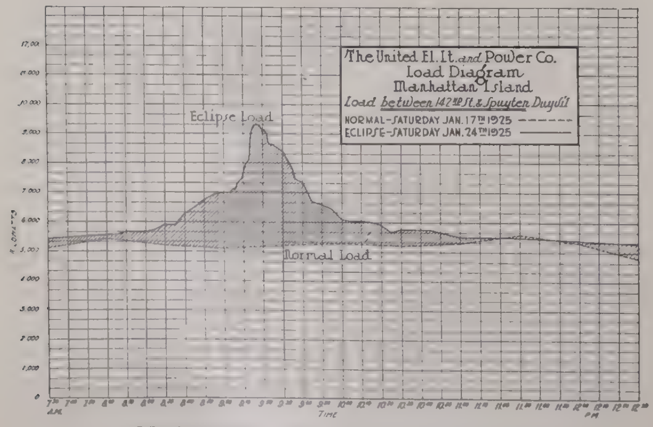

Fig. 10. Manhattan Between 142nd Street and Spuyten Duyvil as Served by the United Electric Light & Power Co.

(**Fig. 8.**) The load for Manhattan south of 73rd Street the morning of the eclipse corresponded closely with the normal load of January 17th before 9:02 and after 10:10 o'clock. Beginning at 9:02, the load rose sharply to a maximum at 9:16, about five minutes after the point of greatest darkness, then gradually declined until it reached normal fifty-five minutes later. An increase of 19.4 per cent above normal was shown at the peak.

The curve of the eclipse load exhibits no unusual phenomena in its rapid rise during the period of increasing darkness, and in its gradual decline afterward.

* * *

(**Fig. 9.**) The eclipse load for Manhattan between 73rd and 142nd Streets began to ascend sharply at 9:00 o'clock, reached a maximum at 9:16, and then descended gradually till 9:35, when it was approximately normal. At about 11:00 o'clock there was a large addition to the load which remained on the lines for the remainder of the morning.

The fact that about two thirds of this district was within the zone of totality accounts for the large percentage increase in load during the eclipse. The addition to the load at 11:00 o'clock was probably due to a power demand, and has no great significance. The excess over normal at peak load was 41.2 per cent.

* * *

(**Fig. 10.**) In the Manhattan district between 142nd Street and Spuyten Duyvil there was a large increase in load over normal between 8:35 and 9:03, then an exceedingly sharp increase until the maximum load was reached at 9:17 o'clock, when the demand was 80.7 per cent in excess of normal. The decline in load after totality extended over a period of a little more than an hour, when the load became nearly normal.

This district was entirely within the zone of totality, which accounts for the great increase in peak load over normal.

(**Fig. 11.**) The load in the Yonkers district did not reach the normal load of the preceding Saturday at any time during the morning although a small peak appeared about 9:22. There was a 3.7 per cent decline from normal.

This was probably due to the fact that the industries in Yonkers did not open as usual, and that the peak at 9:22 was due entirely to a small portion of the lights in residences being turned on by people returning to their homes and offices after viewing the eclipse.

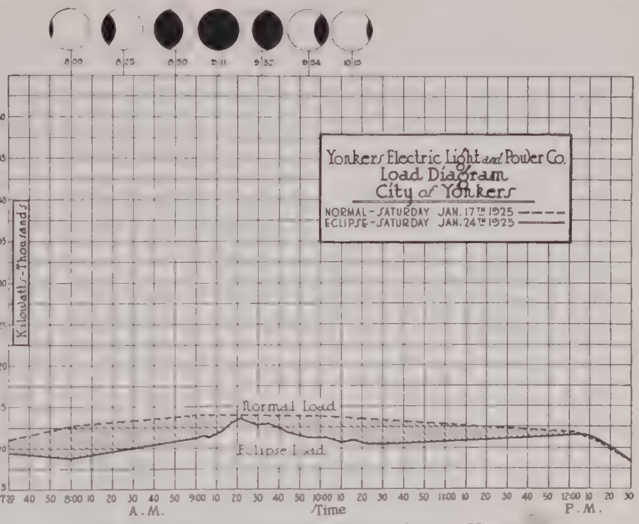

Fig. 11. City of Yonkers as Served by the Yonkers Electric Light & Power Co.

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(**Fig. 12.**) The load in Queens Borough began to rise sharply at 9:03 and reached a maximum at 9:17, showing a 31 per cent increase over normal. It remained considerably above normal for the remainder of the morning.

The load in Queens Borough is largely commercial, and as a result many of the lights which were turned on during the period of darkness at totality were not turned off again during the morning.

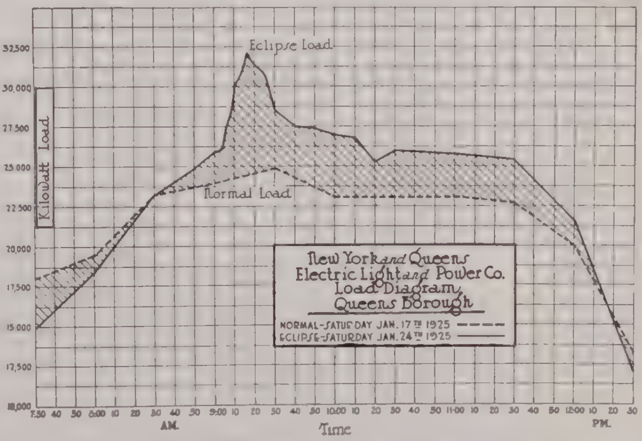

Fig. 12. Queens Borough as Served by the New York and Queens Electric Light & Power Co.

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(**Fig. 13.**) The increase in the eclipse load of Westchester County began at 8:40 and ended with a maximum of 12,456 kilowatts at 9:20 o'clock. The decline in the load continued until about 9:50 when the load became approximately normal.

This curve exhibits no unusual changes in its rise to the peak, and in its fall after totality. The increase was 32.5 per cent.

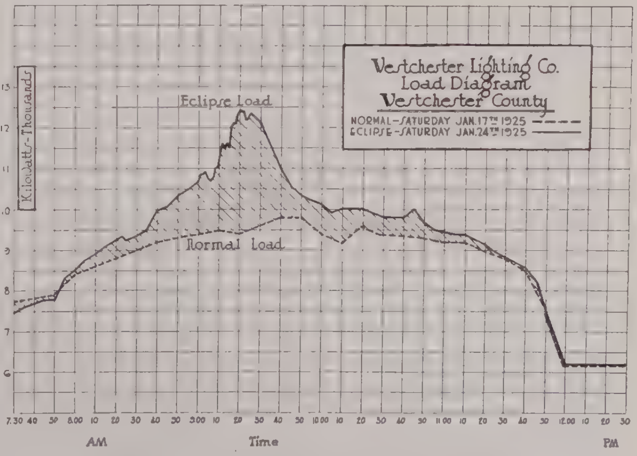

Fig. 13. Westchester County as Served by the Westchester Lighting Co.

High-voltage Dielectric Characteristics of Gaseous Insulators

By Frank M. Clark

Physicist, High Voltage Laboratory, General Electric Company

The day may not be far distant when every town and hamlet from the Atlantic to the Pacific will be included within great inter-connected electric-power networks. Power systems are continually increasing their generating capacity and extending their lines. Considerable growth in these respects will, for reasons of economy, necessitate the use of a higher scale of operating voltages. Thus insulation becomes a paramount factor, in consequence of which we must become better acquainted with the physical and chemical mechanisms by which insulators do their work. We are here presenting a resumé of the high-voltage dielectric properties of gases. While the discussion enters into the realm of electron physics, the subject is presented in so simple a manner that a previous knowledge of the technical elements is not needed for its ready understanding.—Editor.

The real foundation of the electrical advances of the future must be a more thorough understanding of the phenomena accompanying insulation failure. Because of the rapid strides of the past decade toward higher and higher transmission voltages, some of the most serious problems arising are those dealing with dielectric behavior. The present article is an attempt to outline in a general manner the progress which has already been made in the investigation of the properties and laws of gaseous dielectrics, together with a discussion of the various explanatory theories that have been suggested.

Definition of Dielectric

Materials may be divided electrically into two groups, those which conduct and those which do not. The former class contains all those substances which, when placed in an electric field, permit the movement of the charge leading to the complete elimination of the field itself. Hence, there can be no static condition involving an electric field within a conductor. However, when charges are separated by a member of the second group, a non-conductor, their free movement is prevented and the electrostatic field may therefore persist permanently in the medium. This class of substance is designated as a dielectric. In a conductor, the existence of free electrons is generally assumed, the ability of a substance to conduct being determined by the frictional resistance to their movement. In a dielectric, on the other hand, the electrons are firmly attached to the component molecule. When placed in an electric field, this class of substance may and probably does suffer an electronic displacement giving polarity and subsequent molecular movement but, in the absence of free electrons, no motion of the charges leading to the elimination of the field is permitted.

As might be expected in practice, no sharp distinction between conductors and dielectrics is possible. Theoretically even an ideal dielectric remains an insulator only so long as the attraction between an electron and its nucleus exceeds the strength of the imposed electric field or its resultant effects; in other words, only so long as the electronic displacement due to the applied stress does not exceed what might be termed the "elastic limit." Actually, all dielectrics break down under a relatively low electric stress. These facts have gradually led to the belief that the ideal dielectric does not exist, but that the distinction between insulators and conductors is merely one of degree. On this basis a dielectric is defined as a highly resistant conductor. Thus, in such materials, when subjected to stress, considerable electric energy is transformed to thermal energy. This would lead to greater conductivity and heat generation following the laws of metallic conductors until the point where the frictional electronic resistance characterizing the original material is reduced to an extent that the insulating properties are lost. This explanation has led to considerable progress, especially in the field of solid, organic insulators.

In a discussion of dielectric phenomena, the subject matter falls naturally into three groups—the characteristics of gaseous, liquid, and solid materials. Gaseous insulators have furnished a fertile field of research, offering as they do a chemically simple material whose purity can be known and easily varied at will.

Behavior of Gases Under Electric Stress

As a result of the continual improvements in high-voltage apparatus and line insulators, the value of transmission potential has been gradually increasing until a point has been reached where the dielectric strength of air has become one of the important factors in power transmission. Corona losses constitute a factor which cannot be ignored in the practical use of high voltages. For this reason, the problems of corona have been and still are occupying considerable of the attention of research physicists and engineers.

When a difference of potential is applied between the clean smooth conductors of a transmission line separated in air by a distance equal to several times the radius of the wire, the first evidence of change is the appearance of a pale, violet glow surrounding the wires. If the voltage be gradually increased, the luminosity increases, accompanied by a slight hissing sound. The luminosity itself is called the visual corona, the voltage corresponding to its appearance being termed the critical visual corona point. After the corona potential has been applied for a short time, a tuft-like appearance may be noted along the wires, which are entirely covered by the bluish white glow. With direct current, the positive wire seems covered with the characteristic luminosity, the negative presents a tuft-like appearance. As the voltage is slowly increased, the luminous area and hissing sound become more and more pronounced, until such a point is reached that a spark strikes over between the conductors at some chance spot. The appearance of corona is accompanied by considerable energy loss as can be detected by a wattmeter inserted in the circuit.

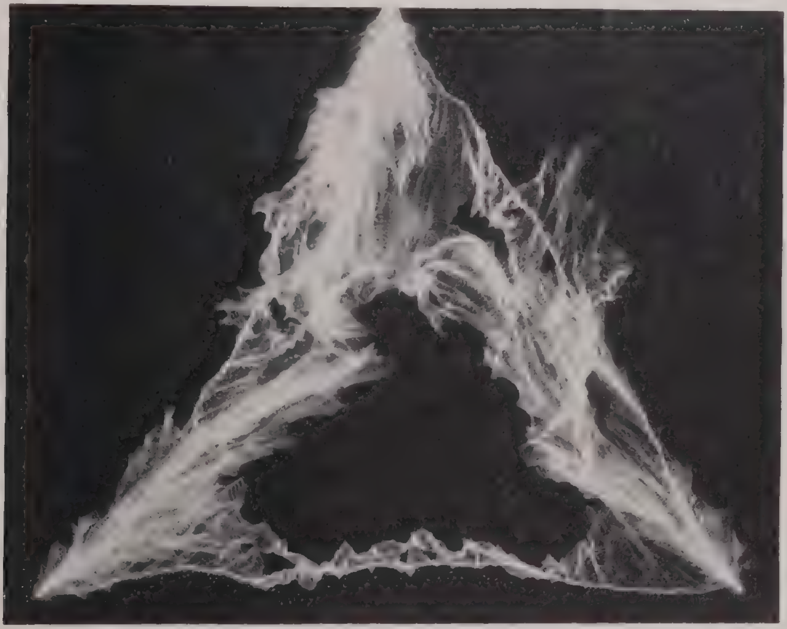

Fig. 1. Million-volt Three-phase Arc Between Sharp Points Spaced Nine Feet Apart. Discharges of this character show an infinite variety of pattern

On the other hand, if the conductors are placed close together, separated by an air space comparable to the radius of the conducting wires, the first appearance of change to be noted with increasing voltage is a sudden sparkover, without the formation of corona. Between the two extremes of spacing lies the point where corona and sparkover appear simultaneously. Sparkover may be described as the electric discharge through a gas between two metallic electrodes. Corona, therefore, is merely an electric discharge through a gas in which the gas itself acts as one of the electrodes.

Of what does this corona luminosity consist? What has happened in a gas, which suddenly has changed from an apparently complete insulator to a conductor allowing a vigorous spark discharge? The fact that the gas has become a conductor indicates the formation of gaseous ions or free electrons resulting in a phenomenon comparable to electrolytic or metallic conduction. Chemically, a change is obvious. Whenever voltage is increased on conductors in air, the peculiarly characteristic odor of ozone becomes evident with the appearance of the luminous discharge. Upon further increasing the voltage, the presence of the various oxides of nitrogen can be detected in the residual gas. If direct current is used and the negative wire is examined after a luminous discharge, it will be found that the wire will present a more or less evenly spotted appearance (Fig. 2). The bright spots are still polished and correspond in position to the negative tufts which have been noted in the luminous discharge. Apparently then, the discharge at the negative wire has been accompanied by the throwing off of metal or metallic oxide particles, the dark spots being oxidized areas resulting from the action of the activated oxygen formed during the electric stress application. It has been estimated by the Bureau of Standards,(1) that, during the tests of solid insulation in air, accompanied as it is by luminous gaseous discharge, about 0.2 of 1 part per million of nitrogen oxides and from 2 to 10 parts per million of ozone are produced.

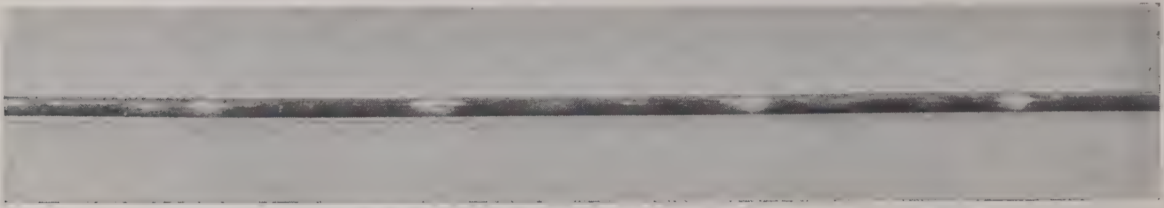

Fig. 2. Section of "Dead" Wire. The bright spots indicate the location of the negative "beads" (*Peek*[10])

Effect of Electrode Material

In view of the fact that metallic conductivity is dependent upon the presence of free electrons held electrostatically in the metal body, according to the electron theory of conduction, it is not surprising that many attempts have been made to explain gaseous breakdown under stress as a function of the electrode materials. Such researches have been given stimulus by the experiments of Elster and Geitel,(2) who found that charged negative particles were emitted by metals under the influence of ultra-violet light and by the more positive metals even under exposure to daylight. Rhubidium, potassium, sodium, lithium, magnesium, thorium and zinc were found to be in the latter class, emitting negatively charged particles on exposure to light in the order named. Copper, platinum, iron, cadmium, carbon and mercury were also investigated, but the effect of light, if any, was too small to be measured. An important phase of these experiments is the fact that when the metals, before exposure to the light rays, are coated with a non-photoelectric film of a liquid such as water, the emission of negative particles is eliminated.

Despite the large amount of research that has been carried out with the purpose of determining the dielectric strength of gases as a function of the electrode materials, no such relation has been found to occur under ordinary circumstances, with the possible exception of Al, Mg and the alkali metals. Under reduced gaseous pressure, Holst and Osterhuis(3) claim to have detected a considerable effect with the use of a cathode of magnesium or the alkali metals. This effect they have found particularly important in the case of the inert gases of the helium family. Upon such results, these authors have founded an interesting theory of gaseous sparkover which we shall later review. It is interesting to note, however, that the electrodes with which Holst and Osterhuis obtain their greatest effect are those which were found by Elster and Geitel(2) to discharge the largest amounts of negatively charged particles under the photo-electric influence of light.

Hobbs(4) has reported that when the electrodes are separated by distances of the order of the wavelength of sodium light, the effect of varying the electrode materials is pronounced. The sparking voltage under these conditions is determined by the metal of which the plates are made and not by the nature or pressure of the gas between them. In this case it seems possible that the spark discharge is carried by corpuscles drawn from the metal and not produced from the gas itself.

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(1) Bull. 2497—Bureau of Mines.

(2) *Wied. Ann.* 38-40, 497 (1889); 41-161 (1890); 42-564 (1891); 43-225 (1892); 52-433 (1894); 55-684 (1895).

(3) *Comptes Rendus*, 175-577 (1922).

(4) *Phil. Mag.* (6)-10-617 (1905).

Table I gives in part the results obtained by Hobbs and shows the relationship for electrodes separated at a distance of about three wavelengths of sodium light.

TABLE I

Metal	Sparking Potential in Volts
Aluminum	185
Brass	220
Magnesium, zinc and bismuth	225
Nickel	245
Silver	270
Antimony	285
Platinum	340

Gaseous insulators, when submitted to electric strain under ordinary conditions, seem to rupture and permit sparkover at a voltage which is entirely independent of the electrode materials. Apparently, the phenomenon occurring in gaseous breakdown is limited to the gas itself and is not affected by contributing causes due to the metallic terminals. However, under certain conditions, experiments seem to indicate that the electrodes may also be involved, even with large electrode spacing. As the gaseous pressure is increased in a sample under test, between aluminum needle points at least 0.1 inch apart, the voltage to produce breakdown increases proportionally. However, when a sparkover voltage is reached equal to about ten times that required under normal conditions, the relation changes and the gas ruptures at about the same voltage irrespective of further increases in pressure. Similar results were obtained in a somewhat different manner by Earhart.(5) With electrodes separated by only minute distances, the rupture voltage seemed unaffected by a change in gaseous pressure from three to one atmospheres. The electric stress under which this phenomenon was observed was of the order of one million volts per centimeter.

A possible explanation of these effects is obtained from the electronic theory of metals. Metallic conductors, as we have seen, are characterized by the presence of free electrons endowed with kinetic energy. Under ordinary circumstances, none of these electrons is able to escape, for should one of the electrons near the surface depart from the neutral metal, being negative itself, it would leave the metal positive and be immediately pulled back by the electrostatic attraction. However, should the kinetic energy of these particles be increased, the possibility of their escape increases proportionally. Such increased energy might be contributed thermally or by the presence of an applied electric field. Hittorf(6) accomplished the result thermally for gaseous sparkover at reduced pressures by raising the cathode temperature to a dull red heat. It seems possible, therefore, that in the researches of Hobbs and of Earhart, either by reducing the space gap between the terminals or by the imposition of high gaseous pressures, it has been possible to apply an electric strain of sufficient magnitude to lead to the liberation of electrons from the metals, whereupon the sparkover voltage becomes roughly independent of the gas itself and acts as a function of the electrode materials.

It is at once evident from the foregoing discussion that an apparent anomaly exists. To cause gaseous breakdown to become dependent upon the electrodes, it has been found necessary in one case to increase the mass of gas between fixed electrodes, which was done by increasing the gas pressure, and in the second case to reduce the mass to an extremely low value, which was done by reducing the electrode spacing to minute gaps. In both of these instances, however, the same result has been accomplished, the value of the mean free path has been changed or its effect altered. In one instance the path was itself reduced by increased pressure. In the other, although unchanged in value, the path was overcome by placing the electrodes extremely close together. The behavior of gaseous sparkover with extreme changes of gas pressure and electrode spacing is an important phase which must be explained by any conclusive theory of gaseous breakdown under electric stress.

Since gaseous sparkover becomes, in part at least, dependent on the electrodes when separated by spacing comparable in order of magnitude to the mean free path, it can be concluded that even with increased spacing the electrodes should have an important function if the mean free paths be increased accordingly. This can be accomplished by the use of reduced pressure. The detailed discussion of the electrical behavior of gases under reduced pressure lies outside the scope of the present article. However, it is interesting to investigate the importance of the electrodes in such phenomena.

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(5) *Phil. Mag.* (6)–1–147 (1901).
(6) *Wied. Ann.* 20–705 (1883).

When an electric discharge passes through a gas at low pressure, the luminous surface of the cathode is surrounded by a dark space, called the Crookes dark space, beyond which a luminous region, the negative glow, occurs. This is succeeded by another dark space and a second luminous area extending to the anode. Under some conditions a larger series of striations may occur. Hittorf(6) has shown that the potential difference between the cathode and the negative glow is independent of the current unless the latter be sufficient to cause the glow to encase the cathode completely, whereupon the potential difference increases with the current. This difference in potential is called the cathode drop and is roughly equal to the minimum potential difference needed to cause sparkover through the gas. Warburg(7) showed that the potential fall was the same for platinum, zinc, copper, silver, and iron, but was diminished with a cathode of aluminum or magnesium. Mey(8) showed that the potential difference fell to extremely low values for a cathode of any of the strongly electro-positive metals. It will be recalled that Elster and Geitel(2) found that even under the influence of daylight, the more strongly positive metals emitted negatively charged particles at ordinary pressure.

The relation between the material composing the cathode and the cathode fall of potential in hydrogen at reduced pressure was found by Mey to be as shown in Table II.

It will be noted that the relationship of the metals in this table is in agreement with the results obtained by Hobbs for sparkover in gases at normal pressure using minute spark gaps.

Influence of Electrode Shape

The electric intensity resulting in corona formation and sparkover, although under ordinary circumstances independent of the material of the electrodes, is greatly affected by their shape. Thus the strength of air measured between parallel plates at normal temperature and pressure is about 30 kv. per cm. For spheres, so placed that the electric field is fairly uniform, approximately the same strength is obtained. As the spheres are further separated, the field becomes more divergent and the rupturing voltage gradient (volts per centimeter distance between the electrodes) decreases rapidly, even reaching a value of the order of two kilovolts per centimeter for large gap spacings. For needle point electrodes, the strength of air may vary from 5.5 kv. per cm. for a 75-cm. spacing to a value of 10 or 12 kv. per cm. for very small gaps. At the surface of very small wires, the dielectric strength of air increases to extremely high voltages.

TABLE II

Electrode Material	Cathode Drop
Platinum	300
Silver	295
Copper	280
Iron	230
Zinc	213
Aluminum	190
Magnesium	168
Sodium	185
Potassium	172

Fisher(9) has investigated the strength of air as a function of the sharpness of needle electrodes. He has found that in passing from blunt points to very sharp needles there exists a degree of sharpness for which the sparking voltage corresponding to a given gap is a minimum, being increased when the electrode shape is changed in either direction. Thus, for example, with a 10.67-mm. gap, the minimum sparking voltage was 6.2 kv., which occurred between needle points 0.038 mm. in diameter. With a 16.4-mm. gap, 0.043-mm. needles gave a minimum sparking potential of 10 kv.

From the behavior of air between needle points, it might be assumed that its strength was in some way related to the diameter of the testing electrodes. This same assumption is possible in the case of parallel wires. It has long been known that air is apparently stronger at the surface of small conductors than large ones. This has at times been explained as due to a condensed air film on the surface of the conductor. Such a film would have a greater relative effect for smaller conductors. On the other hand, if this explanation were true, we should meet with a decided variation in the electric strength of air with various electrode materials. Dense metals such as tungsten should exhibit a higher critical gradient than the lighter metals. However, the experiments performed by Peek,(10) using conductors of tungsten, copper, aluminum, and iron have shown that the gradient is not affected by the material or density of the conductor. Peek(11) has suggested a satisfactory explanation for the phenomenon observed, to which we shall refer in detail later. He assumes that air under given conditions of temperature and pressure has a definite and constant strength, *Gv*. To cause rupture a finite amount of energy is required. This may be the kinetic energy of charged particles moving under the effect of the electric field. Such being the case the gradient at the conductor surface must be sufficient to supply the needed energy, so that at a finite distance from the conductor these particles are endowed with an energy equal to the electric strength of air, whereupon corona and rupture of the gas result. In other words, a finite thickness of air must be under a stress equal to or exceeding the value, *Gv*, representing its assumed strength. To show the relation between the strength of air at a finite distance from the conductor and the conductor radius, Peek has evolved and cleverly proved the authenticity of the formula

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(7) *Wied. Ann.* 31–545 (1887); 40–1 (1890).

(8) *Verhand Deutschen Physikalischen Gesellschaft.* 5-72 (1903).

(9) *Trans. Int. Elec. Congress II*—294 (1904).

(10) *Dielectric Phenomena in High Voltage Engineering*—1st edition, page 46.

$$Gv=29.8\ (1+\frac{0.301)}{\sqrt{r}}\ \text{kv. per cm.}$$

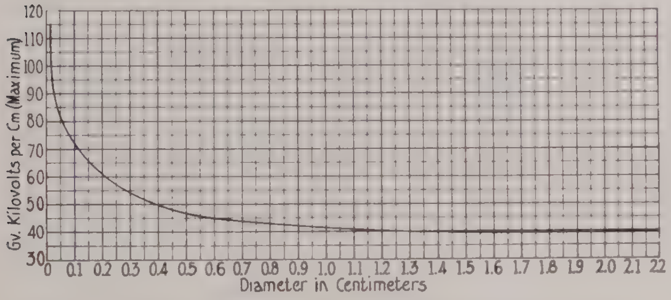

Fig. 3. Variation of Visual Critical Gradient with Size of Wire (*Peek*10)

The distance from the conductor surface to the point where the strength of air is of constant value is called the "striking distance." The presence of such a striking distance is the fundamental cornerstone of the modern theory of gaseous breakdown under stress.

Effect of Spacing Between Conductors

Peek's work(10) on the relation of the conductor radius to the dielectric strength of air leads to the conclusion that the applied voltage to produce sparkover should increase as the spacing between the electrodes is diminished to a distance less than the striking distance. Thus, if the air around a conductor is of greater apparent strength within a distance equal to $0.3\sqrt{r}$, conductors separated by a spacing less than this value should demand an increased difference in potential to produce rupture. This has been found true by many investigators. The effect can easily be demonstrated by an experiment. If two flat parallel electrodes are gradually brought close together in air, the voltage to cause sparkover will finally reach a minimum value beyond which increased potential differences are demanded. At this point, the electric spacing is within the so-called striking distance field. If, on the other hand, a spherical electrode is substituted for one of the plane-surface terminals, no increase in the potential gradient is observed, as the spark gap is diminished until the order of separation is of an extremely small value. However, it will be found that the location of the spark discharge on the spherical surface will change during the experiment. For the larger gaps, the spark length will be the equivalent of the shortest distance between the electrodes. As the sphere is brought nearer the plane surface, the starting point of the discharge will shift away from the nearest point of contact. In this way the spark length will adjust itself to a value corresponding to that which demands the least potential difference. Under carefully maintained conditions, the spark length in such an experiment will roughly correspond to the striking distance, except in the case of very minute gaps.

The experiments of Peek have shown that for equal spacing the spark potential increases with the radius of the spherical electrodes. For a spacing smaller than the diameter of the sphere, corona and sparkover occur at the same voltage. Corona alone is formed when the gap between the electrodes is of such a value that the voltage required for discharge between the spheres exceeds that required to establish a critical stress in the air layers surrounding the spheres to a critical depth.

Variation of Dielectric Strength with Temperature

It has been suggested that the extraordinary strength of air surrounding the surface of conductors of small radii can be explained on the assumption that a finite distance is needed through which the moving gas particles acquire an energy sufficient to result in electrical breakdown. That the seat of failure is entirely in the gaseous field under ordinary circumstances is substantiated by the fact that the breakdown seems entirely independent of the electrode materials. If we therefore assume that gas particles moving under the influence of the electric field are responsible for electric failure, we are at once confronted by the problems of pressure and temperature. With increased temperature, gas particles, as we know from the fundamental laws of physics, are endowed with increased kinetic energy which should, therefore, become evident in a lowering of the breakdown voltage. Furthermore, the kinetic motion of charged particles in a gas should be affected by any factor tending to modify the mean free path, that is, by variations in volume resulting from changes in the imposed pressure.

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(11) A.I.E.E. 30—June, 1911.

Whitehead(12) has investigated the effect of temperature upon the dielectric strength of air surrounding a copper wire 0.276 cm. in diameter. With an ambient temperature varying from 6 to 41 deg., the dielectric strength was found to suffer a loss or gain of 0.22 per cent for each Centigrade degree rise or fall from the standard accepted (21 deg. C.). Ryan(13) in a similar investigation previously carried out had found somewhat similar results (0.27 per cent).

Pressure Effects

We know from Boyle's law that at constant temperature the volume of a gas varies inversely as its pressure. This is readily explained on the assumption that at constant temperature in a perfect gas, each particle retains permanently a definite kinetic energy, unaffected by the elastic collisions with other particles. By forcibly decreasing the volume, therefore, an increase in the number of collisions per unit surface of the retaining walls of the vessel is obtained, resulting in increased gas pressure. To rupture a gas electrically, we have assumed that a definite kinetic energy is transferred to the moving gas particles. Such a transfer demands time and finite distance in which to be manifested. This distance we have called the striking distance. Thus we can readily see what will happen if we increase the pressure on a gas under electric stress. We first cut down the mean free path of the moving particles. This tends to prevent the manifestation of that fraction of the kinetic energy derived from the field itself. As a result, greater energy transfer must be obtained to offset the shortening of the mean free path. In other words, gas under pressure should demand higher voltages in order that the kinetic energy of its particles may be brought to such a value that ionization leading to corona formation and rupture will occur.

These predictions are borne out by experiment. Thus, starting with air at room temperature and pressure under a fixed spark gap, the strength varies directly with the pressure in either direction. This relation, however, does not hold true indefinitely. Ekern(14) has found, for example, that when the potential to spark over between needle points with a one to three-tenths of an inch gap has increased with the pressure to a value roughly ten times that needed under normal conditions, breakdown occurs at about the same potential, irrespective of the pressure. At the other extreme, Carr(15) has found that with diminishing pressures the electric strength of air falls off to a minimum beyond which further reduction in pressure leads to increased strength. The pressure corresponding to this minimum spark potential is called the critical pressure. The minimum spark potential is constant irrespective of the gap distance.(16) The critical pressure, however, varies inversely as the spark length.

TABLE III

VARIATION OF CRITICAL PRESSURE WITH SPARK LENGTH IN AIR

MINIMUM SPARK POTENTIAL 341 VOLTS

Spark Length in Mm.	Critical Pressure in. Mm. of Hg.	Product of Spark Length × Critical Pressure
0.005	890.1	4.45
0.010	450.7	4.50
0.025	184.8	4.62
0.050	94.62	4.73
0.125	38.01	4.75
0.500	10.21	5.10
1.000	4.98	4.98
3.000	1.89	5.67
5.000	1.34	6.70
10.000	0.67	6.70

Simultaneous Variation of Pressure and Spark Gap

The change of the electric strength of a gas with pressure brings up the question of the relation existing between dielectric strength on the one hand and on the other the simultaneous variation of gas pressure and spark gap distance. Physically, we know that changes in the pressure imposed on a gas between two electrodes merely result in a variation in the mass of the gas in the intervening space. Thus at reduced pressures fewer gas molecules per unit volume would be found in the spark gap area. However, this effect could be counteracted within limits by separating the electrodes to greater distances. Therefore, if the determining factor in breakdown is the mass of gas between the electrodes, the sparkover voltage should remain unchanged if the pressure and the gap distance are simultaneously changed to the correct extent. This has been found to be true. As a result of an extended series of researches with various gases, Paschen(17) found that the difference in potential necessary to produce a spark depended only upon the spark length and gaseous pressure. If both were altered in such a way that their product gave a constant value, the mass of gas between the electrodes remaining unchanged, the sparking potential was unaffected.

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(12) *A.I.E.E.* 29-(2)-1154 (1911).
(13) *A.I.E.E.* for 1904—page 101.
(14) *Sibley Journal of Eng.* 18-391 (1904).
(15) *Proc. Royal Soc.* 71-374 (1903).
(16) *Proc. Royal Soc.* 52-99 (1892).

The results in Table IV are for air and were taken from Paschen's paper to illustrate how nearly the relationship holds within the limits studied.

TABLE IV

Air Pressure in Om. of Hg.	Spark Length in Cm.	Sparking Voltage in Electrostatic Units
10	0.75	16.23
15	0.50	16.54
20	0.38	16.75
25	0.30	17.00
30	0.25	16.83
40	0.17	16.86
50	0.15	16.68
75	0.10	16.63
		Average } 16.65

In this table, the product of the pressure and spark length is maintained at 7.5. It will be noticed that in the tabulation the pressures investigated are far above the critical pressure at which the minimum spark potential occurs. Thus, Carr(15) found that the critical pressure for a spark gap of 0.1 cm. was 4.98 mm. of mercury. Carr has found, however, that the relationship established by Paschen still holds even with pressures approaching the critical gas pressure. The variations in the product of the spark length and gas pressure shown in Table III are well within the limits of experimental error for such small gap distances.

Hagoshi(18) has extended the researches of Paschen and Carr to the field of high pressures and has found that the relation established by Paschen does not hold under these conditions. The voltage increase for extremely high pressures is somewhat less than expected.

Previous Ionization

An interesting part in relation to the mechanism of gaseous failure under electric stress is the effect produced by ultra-violet light, the presence of gases from flames or electric arcs, or the exposure of the gas under test to Rontgen rays. These agents tend to reduce the time lag occurring between the voltage application and the resulting spark. They produce no effect on the sparking voltage itself. It is known that gases from flames and arcs contain ions. Rontgen rays when passed through a gas ionize it and thus give the gas conducting properties. This effect can be detected by the discharge of an electroscope. From this we may conclude that the introduction of ionized gas or ionizing agents is effective in gaseous rupture.

Compton and Foulke(19) have found that the formation of corona leading to sparkover in air is greatly affected by the radioactive radiation from the earth. By the use of pure air and the protection of the spark gap from the earth's radiation by means of a lead shield, it was found possible to reduce the number of ions to such an extent that the discharge was started with great difficulty. On the other hand, by exposing the spark gap area to radioactive emanations, it was possible to reduce the time lag to extremely small values.

The effects produced by the presence of ions or ionizing agents in a gas under electric stress bear an important relation to the theory of the mechanism of gaseous failure. If the time lag preceding sparkover is reduced by the presence of these materials, it must be that during this period the process of ionization is taking place. When sufficient conducting bodies are produced, electrical breakdown results. No appreciable current can be detected with an electroscope before the beginning of the visual corona.

The Time Factor

We have assumed that the failure of gaseous dielectrics under electric stress is preceded by a transfer kinetic of energy to the gas molecules. These energized molecules then proceed in some manner to increase the conductivity of the gas, leading to breakdown. Such a sequence would naturally demand a time factor. Under ordinary conditions apparently no such factor exists. For a definitely shaped electrode and spacing distance, breakdown seems to occur at once when the critical voltage is reached. However, Hayden and Steinmetz(20) by the use of high voltages for an extremely short time (transient voltages) were able to detect a time lag between the application of the critical stress and breakdown. Fig. 4 illustrates the relation between the time and voltage factors.

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(17) *Wied. Ann.* 37–79 (1889).
(18) *Ann. Physick.* 4–45–431 (1914).
(19) General Electric Review. 26–756 (1923).

For a definite gap, the disruptive energy of oil is roughly 30 times that of air. Thus the oil gap will demand greater time to puncture than a similar gap using air as the dielectric, so that the air gap can be used as a protection for the oil gap against momentary voltages of high value.

Changes with Frequency

With highly polished electrode surfaces, there seems to be but a negligible effect due to frequency when increased from 25 to 40,000 cycles per second. With unpolished terminals, however, frequency assumes increasing importance. This can be explained in connection with the increased power loss. In the presence of rough spots on the electrode surface, gaseous failure may occur at considerably lower voltages with increased frequency. This generally occurs in the form of small streamers beginning at the rough spot. The loss is small, however, and the effect is not general. With high frequency, the streamers once begun result in high losses. This distorts the field and a general breakdown results. It is probable that the energy loss begins at the rough spot at the same voltage with high or low frequency. When once started at high frequency, however, the greater loss results in considerable distortion of the field leading to an apparently diminished electrical strength for the gas.

Effect of Humidity

Using gas dried with extreme care, Thomson has found that an electric intensity could be applied between parallel plates as high as three or four times that sufficient to produce spark discharge under the same conditions for air containing traces of water vapor. When once the spark has started, however, the potential difference falls to that obtained with moist air and the sample recovers its original high strength only after a considerable rest period.

Peek,(21) Whitehead(22) and others have found that with sphere gap electrodes but little if any effect is produced on the sparking potential of air with a relative humidity varying up to 90 per cent. In the case of needle gaps, the disruptive potential increases with the humidity. Peek suggests that "the formation of corona streamers in humid air may cause a fog and then agglomerate the water particles which, in effect, increase the size of the electrodes."

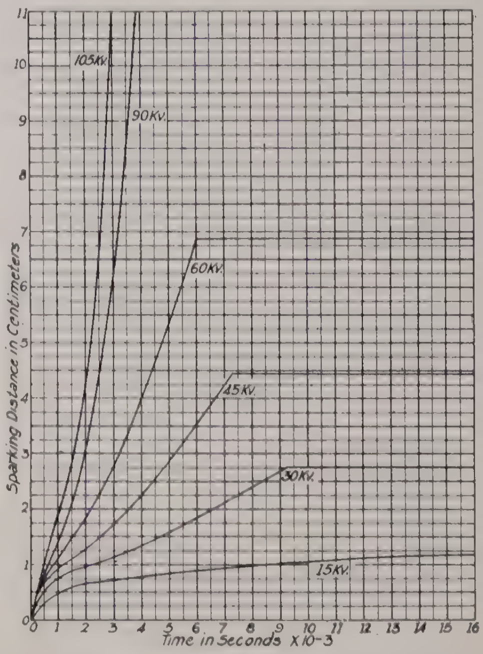

Fig. 4. Relation Between Flashover in Air and Time for which Voltage is Applied Using Needle-point Electrodes. The horizontal lines give the constant-voltage striking distance (*Steinmetz and Hayden*[20])

In the case of parallel wire electrodes, changes in the relative humidity produce little if any effect on the point at which corona and energy loss start. When the humidity has reached such a value, however, that moisture condenses upon the electrode surface, there results a considerable lowering in the potential difference necessary to produce corona and sparkover. This is of considerable importance in outdoor aerial wires.

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(20) *A.I.E.E.*- 29-1125 (1910). See also Peek: *A.I.E.E.* for 1915, page 1695.

(21) Dielectric Phenomena in High Voltage Engineering—1st edition, page 88 (1915).

(22) *A.I.E.E.* 29-1175 (1910).

Energy Loss

It has been observed that corona formation does not occur until air has been overstressed through a finite distance. Energy loss shows a similar behavior and becomes of importance only with the formation of visual corona.

In practice, a perfectly smooth transmission line never occurs. Rough spots are ever present in the form of scratches, etc., which result in electrical stress concentrations leading to a higher local gradient than that present on the adjoining conductor surface. In some cases, the critical voltage value for corona may be lowered as much as 33 per cent through the presence of rough spots.

Elster and Geitel,(23) after an extensive series of experiments, concluded that the rate of electrical leak from a transmission line varied considerably with the weather conditions. It was very much smaller in a foggy atmosphere than when the weather was bright and clear. This agrees with the earlier investigations of Zelensky,(24) who found that the discharge currents in air are lowered by an increase in humidity, probably due to decreased ionic velocities. Thus a negative ion in dry air under the influence of a difference of potential of one volt per centimeter moves with a velocity of 1.87 cm. per sec. In moist air, the velocity decreases to 1.51 cm. per sec. In view of the findings of later researches, it seems probable that this decreased velocity is due to the hydration of the ionic bodies leading to the formation of slow moving complexes.(25) (26)

The effect of sleet or rain on a transmission line leads to increased losses. This is illustrated in an experiment cited by Peek. "Two parallel dry cables were slowly brought up to the critical voltage value. Water was then thrown on the cables. What had been a glow on the surface of the dry cables now became, at the wet spots, a discharge extending as much as 5 to 8 cm. from the cable surface." After running at the same voltage for several moments, the wires became quite dry and returned to their normal discharge values.

Dielectric Strength of Various Gases

In the preceding discussion of the behavior of gases under electric stress, it has been tacitly understood that the various factors mentioned apply to all gases. From this, however, it must not be assumed that all gases possess the same insulating properties. This conclusion might erroneously be drawn from the fact that the breakdown of gases seems largely dependent upon the temperature, electrode shape, gap spacing, etc. While it is true that the conditions of test affect the dielectric strength of all gases in the same way, each gas, nevertheless, possesses its own characteristic electrical as well as physical and chemical properties.

From the fact that flashover in gases is greatly affected by any condition tending to change the value of the mean free path, Rontgen(27) reached the general conclusion that the sparking potential for a definite spark gap depended only on the mean free path of the gas molecules. Thus all gases should possess the same minimum sparking potential. This we know is untrue. The minimum sparking potential for several of the common gases, together with the values of their mean free paths at atmospheric pressure, is given in Table V.

TABLE V

Gas	Minimum Spark Potential in Volts	Mean Free Path $\lambda \times 10^5$ cm.
Air(28)	341	0.95
Oxygen(29)	455	1.05
Nitrogen(28)	251	0.98
Hydrogen(28)	302	1.8
Helium(28)	261	2.6
Sulphur Dioxide(29)	457	0.48
Carbon Dioxide(29)	419	0.68

The values of the mean free paths with the exception of helium were taken from O. E. Meyer's "Kinetische Theorie der Gase," page 142. That for helium is the value suggested by J. J. Thomson(30) from calculations based on the viscosity measurements of Lord Rayleigh.(31)

Theoretical Considerations

The apparent increase in the sparking potential of air with small gap spacings led Steinmetz to suggest the presence of a layer of "condensed air." This idea has been abandoned.(32) In its place has risen the belief that the dielectric strength of a gas is of a constant and characteristic value. Peek, as has been shown, suggested that the real strength of air is that value obtained at a distance of $0.3\sqrt{r}$ from the conductor surface.

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(23) *Ann. der Physik* ii–425 (1900).
(24) *Phil. Mag.* 46–120 (1898).
(25) *Washburn Technology Quarterly.* 21–288 (1908).
(26) J. J. Thomson—The Electron in Chemistry (1923) page 75.
(27) *Gottingen Nach.* 390 (1887).
(28) Strutt: *Phil. Trans.* 193–377 (1900).
(29) Carr: *Proc. Royal Soc.* 71–374 (1903).
(30) Conductivity in Gases, J. J. Thomson, page 450.
(31) *Proc. Royal Soc.* 69–198 (1896).
(32) *A.I.E.E.* 30–92 (1911).

r being the radius of the testing electrodes. Within this distance the dielectric strength shows marked increase. The existence of this so-called striking distance contributes strong evidence in favor of the collision theory of gaseous breakdown as suggested by Townsend.(33)

Briefly, the theory enunciated by Townsend seeks the cause of electrical failure in the generation of conducting particles by the successive impacts of free electrons against the neutral gas molecules. The theory is best explained by an illustration. Suppose two oppositely charged plates are separated by air. The free electrons present receive an accelerated motion due to the electric field. With the gradual increase in potential, the electrons acquire increased kinetic energy until such a voltage value is reached where corona is observed. At this point the particles originally present have become endowed with sufficient kinetic energy from the electric field to generate more conducting particles by impact with the neutral gas molecules. This increase in the number of charged bodies leads to a rapidly mounting current between the plates and the ultimate electrical failure of the gas. Such a phenomenon involving energy transfer demands both time and energy-distance. The time factor we have seen to exist. The energy-distance phenomenon is called the striking distance. The existence of a "condensed air layer" with an apparently high dielectric value is merely the manifestation of this energy-distance relation.

The current-voltage relation in sparkover phenomena is illustrated in Fig. 5. In this case it is assumed that a difference in voltage is applied between two parallel plane electrodes separated by air. When the direct-current voltage is slowly impressed, the electrons present are caused to migrate toward the positive plate. The rate and amount of this migration determines the current effects produced. The electron drift at first increases with the voltage (area A) and then reaches a value beyond which the difference in potential produces little if any effect (B). Under these conditions, all the electrons present are being attracted toward the anode, each having a share in producing the so-called saturation current observed. With further increase in potential, however, a point is finally reached when the current between the electrodes increases rapidly with but little change in voltage (C). This current increase is accompanied by luminous discharge. Townsend's explanation of this effect would be that, with slowly mounting voltages, the energy transfer to the moving electrons assumes greater and greater values until a point is reached where the electron has become endowed with sufficient kinetic energy to ionize the neutral molecules by collision. Under these conditions the number of charged particles and therefore the current, increases with no further change in the applied voltage. The discharge is accompanied by luminosity, and with sufficient voltage gradient it leads to the generation of enough conducting particles to result in flashover.

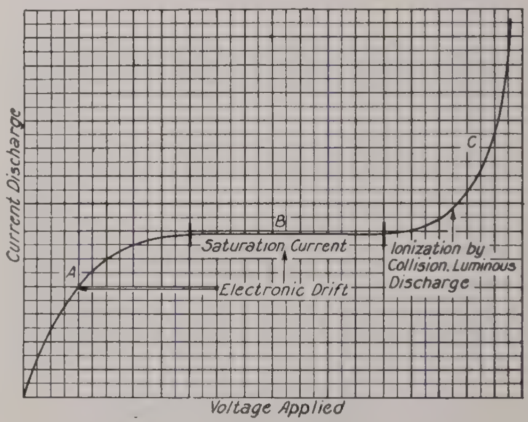

Fig. 5. Current-voltage Characteristics in Gases

The mechanism of corona formation and spark discharge is therefore similar to the ionization of a gas on exposure to the effects of alpha and beta rays from radioactive materials. It has been observed by Rutherford and others that the path of an alpha particle is straight up to the point where the velocity has been reduced to such a value that it is no longer able to ionize a neutral molecule with which it may collide. Beyond this point, the path becomes deflected and may end abruptly should a "head on" collision occur. The beta particles being of lighter mass, show the deflection effects of collision to a greater extent. The study of the ionization phenomena due to alpha and beta particles has been responsible in no small degree for the Rutherford-Bohr concept of atomic structure.

The Ionization by Collision Theory

The Townsend theory, which attributes gaseous insulation failure to ionization by collision, has received wide acceptance. Perhaps the best illustration of its value is to be obtained from a review of the manner in which it explains the observed behavior of gases placed in an electric field.

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(33) *Trans. Int. Elec. Congress*—St. Louis I-106 (1904).

Effect of Electrode Material

If the seat of gaseous failure is in the gas itself, it should be independent of the electrode materials. Under ordinary circumstances this is true. Dushman(34) has shown mathematically that the field strength to extract electrons from thoriated tungsten is of the order of $10^7 \times 3.9$ volts per centimeter. It seems improbable therefore that electrons or ions obtained from the electrodes can play an important part in gaseous dielectric failure.

Source of Primary Ions and Electrons

The theory demands an initial source of ionic or electronic supply. This, Compton and Foulk(35) have shown, can be obtained from the effects of the radio-active emanations from the earth's crust.

Change of Dielectric Strength with Electrode Spacing

With large spark gaps, the longer free paths of electronic motion assume increasing importance. Since ionization by collision depends upon the manifestation of the kinetic energy of the electron, it is obvious that with spacing comparable to the longest free paths, a minimum of potential should be required. With smaller electrode spacing, the effective free paths are reduced, thus demanding increased electric stress to supply the required electronic velocities. The dielectric strength of a gas can therefore be defined as of that value occurring with the greatest limiting electrode spacing, within which spark can not form except by the increased value of the electric field. With voltages below this critical value, all ionization ceases due to the decreased electronic velocity. With this distance all the electronic free paths are involved; with decreased distance, the effective free paths are reduced.

Are the Electronic Impacts Elastic?

Concerning this phase, there arises a difference of opinion among physicists. The question is of importance, for with elastic collisions, the ability to ionize should be permanently retained by the colliding electron.

Eldridge(36) has concluded that in ionization by collision the electron loses its total energy even though this exceeds the ionization potential of the gas. The electron which is the product of the ionization appears to possess negligible energy at the moment of its escape.

Compton(37) has concluded that for electronic velocities below a definite critical value, characteristic for each gas, collisions with gas molecules are probably elastic since neither radiation nor ionization results.

Franck and Hertz(38) suggest that the electron possesses a critical velocity, below which on collision with gas molecules no energy loss is observed and above which the electron loses all of its energy. This agrees with the quantum theory as applied by Bohr in his concept of atomic structure.(39)

Are Successive Impacts Required for Ionization?

Compton(40) accounts for ionization as a result of successive impacts. When the electronic velocity is of sufficiently high value, its energy may be transferred to a neutral molecule in collision. If this latter be again struck while in this "activated" condition, ionization may occur if the total energy of the two colliding electrons exceeds that corresponding to the minimum ionizing potential.

Characteristics of the Secondary Electrons

Rosseland(38) concludes that the velocity of the electron expelled during collision is less than that of the primary electron. In the case of helium, the ionizing potential for two electrons expelled simultaneously is more than twice that required for the removal of one.

Effect of Positive Ions

In the generation of free electrons by collision of electrons and gas molecules, the molecular residue possesses a positive charge and moves under the influence of the electric field. Due to its relatively great mass, however, the positive residue demands too long a free path and too large a potential difference to become of more than negligible ionizing value.

Are Electrons Emitted from the Negative Plate?

The theory of ionization by collision carried to the extreme suggests that the impact of the positively charged residue against the negative electrode might cause it to act as a seat of electron emission. No experimental evidence of such an effect has been found. The value of the saturation current is a direct measure of the total number of electrons set free per unit time. This value seems independent of the velocity of the positive ion and its impact against the negative electrode.

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(34) *Trans. Am. Electro-Chem. Soc.* 44–101 (1923).
(35) GENERAL ELECTRIC REVIEW. 26–756 (1923).
(36) *Phys. Rev.* 20–457 (1922).
(37) *Phys. Rev.* 22–333 (1923).
(38) *Phil. Mag.*, January, 1923, page 65.
(39) *Phil. Mag.* 6–26–1 (1913); 6–26–857 (1913); *Nature* 107–104 (1921).
(40) *Phys. Rev.* 15–477 (1920).

Holst and Osterhuis(41) have claimed that the material composing the cathode is of major importance in sparkover with members of the helium family. The effect, however, is supposedly produced through electrostatic attraction rather than by positive ion impact and is confined to discharge through the monatomic gases between electrodes of magnesium or the alkali metals at a gaseous pressure corresponding to that of the minimum sparking potential. The problem of withdrawing electrons from the cathode is a function of the thermionic equation of Richardson.(42) This has been mathematically extended by Dushman(43) from the standpoint of the Nernst heat theorem. Dushman's equation suggests a field strength of the order of $10^7 \times 3.9$ volts per centimeter to cause electronic emission from cold thoriated tungsten. The effect of the metallic electrodes as contributing causes to gaseous breakdown is admittedly negligible at ordinary pressures with gases other than those of the helium family. This, Holst and Osterhuis declare, is due to the loss of energy occurring with the less elastic electron-molecular collisions in the common gases under the usual conditions. The problem of electron emission from hot and cold metals has assumed great importance within the past few years. Widespread research has resulted in considerable knowledge of the phenomenon of thermionic emission.(44) The problem of the cold electrode and its importance in dielectric failure is attracting increasing attention from the research engineer and physicist.

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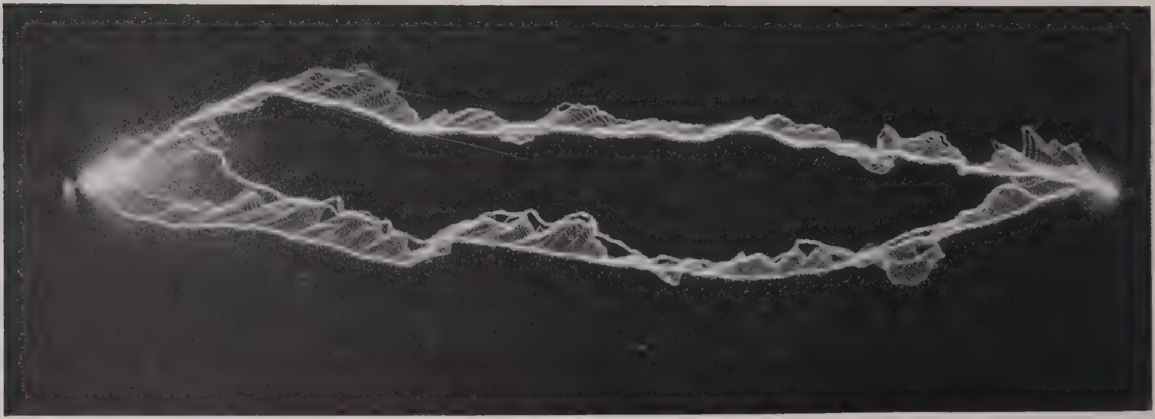
(41) *Comptes Rendus* 175-577 (1922); *Phil. Mag.* 46-1117 (1923).

(42) The Emission of Electricity from Hot Bodies (1921); *Trans. Am. Electro-Chem. Soc.* 21-69 (1912).

(43) *Trans. of the Am. Electro-Chem. Soc.* 44-101 (1923).

(44) *Megh Nad Saha, Phil. Mag.* 40-472 (1920); Tolman, J.A.C., 43-1592 (1921); Dushman and Ewald, GENERAL ELECTRIC REVIEW. 26-154 (1923), etc.



Two Successive 1,500,000-volt Arcs Between Points Spaced 14 ft. Apart. The left terminal is a million volts "above" ground; the right terminal is 500,000 volts "below" ground. Both terminals show brush discharge and two heavy spark discharges and about a dozen successive alternations of arc where the air currents have moved the arc in a direction parallel to the photographic plate

Automatic Substations of the Long Island Lighting Company

By Louis Wintner

New York Office, General Electric Company

Man's hands were the first tools and are still the most versatile in the world. Yet how utterly helpless would be our situation had we to depend entirely upon them for accomplishment! We could throw a stone but could not fashion even the pencil with which we write. And so down through the ages man has devised implements by the aid of which the hand could supply the day's needs. Some of these implements require the hand for every movement, like the needle and thimble; others but once in thousands, as the machine gun; still other wondrously ingenious automatic mechanisms seldom require the hand at all. In adopting the automatic principle, and thereby increasing the capacity of the human hand, no industry has made such great strides as that which manufactures electricity. In the following article Mr. Wintner gives the story of one example, a public utility company that now has 14 automatic stations as an integral part of its system. —Editor.

The territory served by the Long Island Lighting Company embraces the major portion of that part of Long Island which extends from the environs of New York City (Boroughs of Brooklyn and Queens) about 100 miles eastward to Montauk Point, from Long Island Sound on the north to the Atlantic Ocean on the south—an area of about 1000 square miles of varying character and interest.

The district adjacent to the city is distinctly suburban, the northern portion extending over wooded hills clustered around the famous Oyster Bay section, where many of New York's prominent citizens have their country homes and estates. Toward the south the hills recede to the Great South Bay section of many seashore villages and resorts. The middle of the island is more or less rural in character, with a prosperous farming community that supplies New York with much of its fresh produce. The Great Rocky Point Station of the Radio Corporation of America, for which power is supplied by the Long Island Lighting Co., is located here, its huge towered antennas dominating the landscape for miles. Eastward, the middle-land supports extensive truck farms and fruit orchards, with a large poultry industry, bringing great prosperity to this region. Several communities on the eastern shores retain much of the picturesque character which links them to their traditional whaling days; and southward the sand dunes of the Shinnecock Hills possess a charm which has made this region—the environs of Southampton and Easthampton—a center of wealth and fashion.

In the early days of the electric lighting industry, a number of communities scattered about this territory established local lighting plants. The demand made upon these small stations soon outgrew their natural limitations and, as was inevitable, a consolidation was effected. This was accomplished about 14 years ago by E. L. Phillips & Co., Engineers, of New York, and has since grown into a modern and unified system of power generation and distribution. The principal generating stations are located on tidewater at Northport and Glenwood, having a total turbine-generator capacity of 40,500 kw. now in operation and under construction. A tie line extends to the Far Rockaway generating station of the Queens Borough Gas & Electric Co., a 17,500-kw. plant, owned by the Long Island Lighting Co. Power is transmitted at present to the various substations at 13,200/22,800 volts Y, 60 cycles, and is there distributed at 2200 volts, 3-phase, and in some cases 2-phase. The eventual high-tension transmission will be at 66,000 volts, 3-phase, for which about 45 miles of steel pole line is now under construction.

In building the new substations, and modernizing the old ones, special efforts were directed toward the selection of equipment which would insure the maximum reliability of service. An analysis of the operating conditions proved that most of the service failures were due to the lines being short circuited during stormy weather by "treeing." In the smaller outlying districts the cost of substation attendance to insure prompt restoration of service was considered out of proportion to the revenue produced; on the other hand, the loss of revenue resulting from service interruptions, and especially the desire to render to the public the best service, were equally important considerations.

A careful study of automatic reclosing switching equipments led to their selection

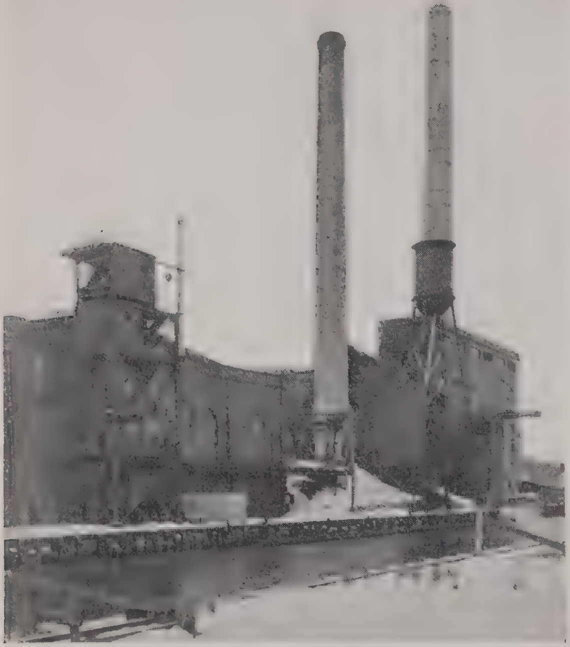


Fig. 1. Far Rockaway Generator Station

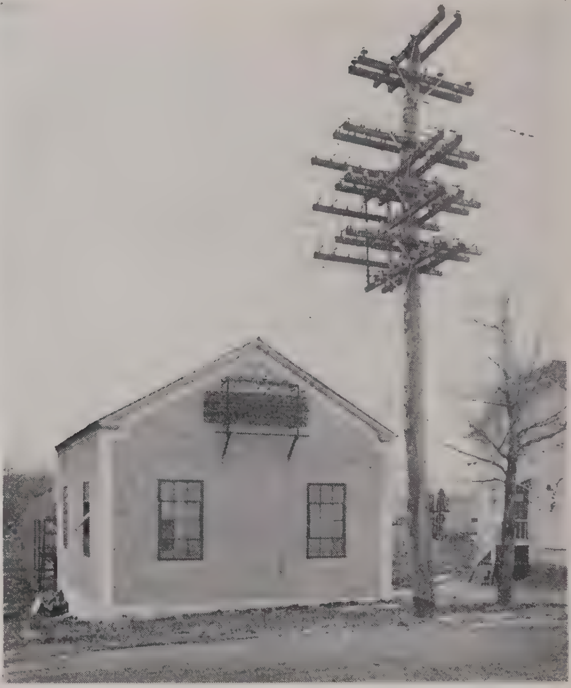


Fig. 2. Port Washington Automatic Substation

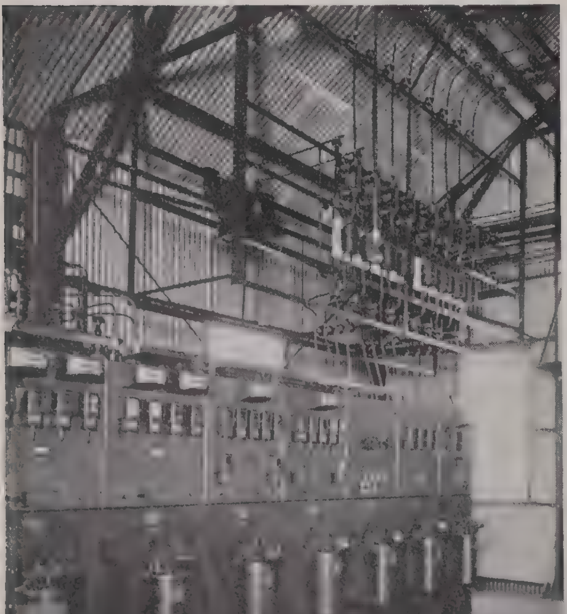


Fig. 3. Floral Park Automatic Substation. Power line construction and automatic switching equipment for a-c. reclosing feeders, and transfer apparatus for two incoming power lines

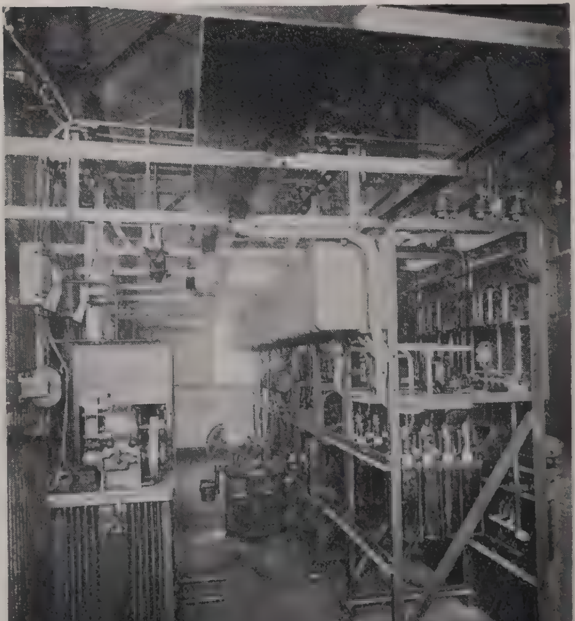


Fig. 4. Floral Park Automatic Substation. Back view of automatic switching equipment for a-c. reclosing feeders, and transfer apparatus for two incoming lines

as best suited to give the desired results. The higher first cost of this type of switchboard is largely offset by its lower installation expense, each panel being structurally designed so that it can be shipped as a completely assembled, connected, and adjusted unit. In this respect it bears a close resemblance to the truck type of switchboard; thus, the setting-up expense is confined to the uncrating and placement of each panel in location, and the coupling of adjacent sections of the buses. A direct economic advantage is gained from the lower operating cost of these equipments, as one patrol attendant is able to take care of several substations, the number depending on the distance between points of control.

Equally important, also, is the reliability of the automatic equipment, designed as it is to correct abnormal conditions by a rigid schedule of operation far more dependable than human manipulation. The management of the Long Island Lighting Co., recognizing in this an opportunity to give to its customers the maximum in continuity of service, has adopted this type of switching equipment for 14 substations, thus setting a high standard of engineering for service to small communities that may well be emulated.

It may be desirable here to enumerate the principal functions of the automatic reclosing equipments. They are:

1. (1) To disconnect a feeder from its source automatically in case of dangerous overload or short circuit.
2. (2) To reconnect the feeder automatically after a definite time. The oil breaker then remains closed if the cause of trouble has meanwhile disappeared.
3. (3) In case the fault remains, the breaker will again trip automatically.
4. (4) After a predetermined time the breaker again automatically recloses, remaining so if the line is clear.
5. (5) If the trouble still persists, the breaker is automatically opened a third time, and remains locked out. Restoration of service is then made manually after the fault has been removed.

Many variations of these typical operations can be obtained. As an example, where a substation is served by two incoming feeders, one normal and one emergency, a failure in the normal feeder will automatically connect the station to the emergency supply. This action can be extended, if desired, to the automatic reconnection to the preferred source of supply when voltage is restored. Another adaptation of this control is in the use of a time switch to govern the automatic reclosing operation where a feeder equipment supplies one or more constant-current transformers for series incandescent street lighting. In case of an open circuit on a series street lighting circuit, there is always a hazard both to the public and the repair man, on account of the high voltage. The elimination of this hazard is accomplished by a relay combination which instantly disconnects the source of supply, locking it out until restored by hand after the series circuit has been reconnected by the lineman. Many other automatic functions can be accomplished to suit special operating requirements.

The following is a list of the several substations now installed and under construction in the territory of the Long Island Lighting Co. The ratings of these stations give an idea of the present practice in securing distribution by means of automatic switching equipment.

Port Washington

One 500-kv-a., 6600-volt, 60-cycle, 2-phase incoming line
One 250-kv-a., 2200-volt, 60-cycle, 2-phase incoming line
Five 300-amp. 2200-volt, 2-phase outgoing feeders
Two 20-kv-a., 2200-volt, single-phase feeders for street lighting

Floral Park

One 400-kv-a., 2200-volt, 60-cycle, 2-phase incoming line
One 500-kv-a., 4400-volt, 60-cycle, 2-phase incoming line
Two 2200-volt, 300-amp., 2-phase outgoing feeders
Two 20-kv-a., single-phase outgoing feeders for street lighting

Farmingdale

One 600-kv-a., 13,200/2200, Y-primary, 2300-volt secondary, 3-phase, 60-cycle incoming line
One 450-kv-a., 2300-volt, 3-phase outgoing feeder
One 250-kv-a., 2300-volt, 3-phase outgoing feeder

Lynbrook (Queens Borough Gas & Electric Co.)

Two 1000-kv-a., 13,200-volt, 60-cycle, 3-phase incoming lines
One 800-kv-a., 2300-volt, 60-cycle, 2-phase incoming line
Two 2300-volt, 300-amp., 2-phase outgoing feeders
One 2300-volt, 22.5-amp., 2-phase outgoing feeder for street lighting
One 2300-volt, 7.5-amp., single-phase outgoing feeder for street lighting

Garden City (Outdoor substation)

Four 2200-volt, 300-amp., 60-cycle, 2-phase outgoing feeders
Two 2200-volt, 10-amp., single-phase outgoing feeders for street lighting

(The automatic reclosing equipments in Garden City substation are enclosed in steel housings for outdoor installation.)

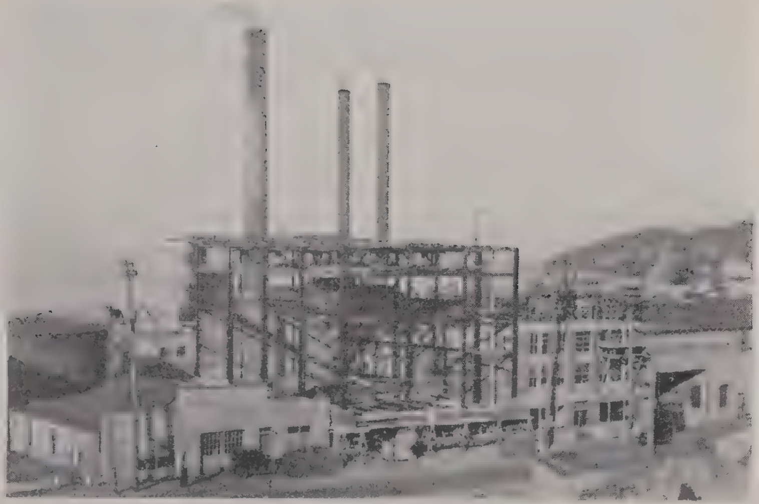


Fig. 5. Northport Generating Station

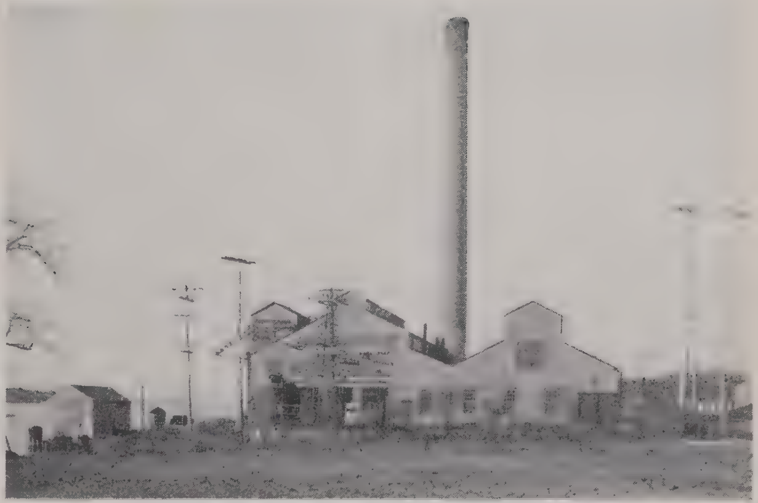


Fig. 6. Glenwood Generating Station

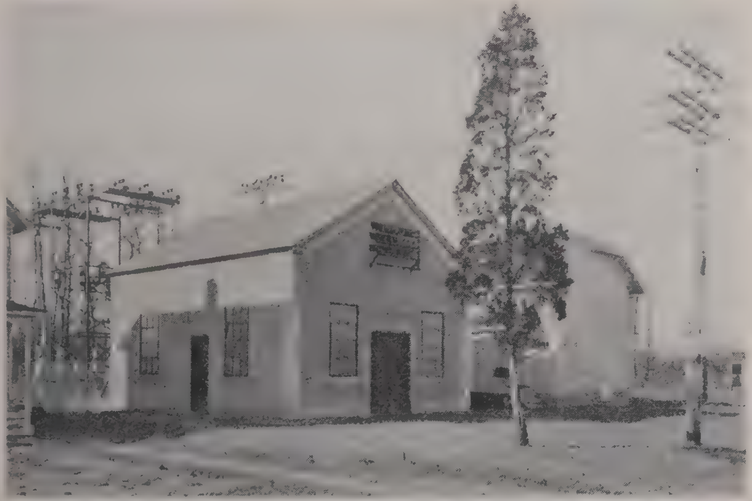


Fig. 7. Bellmore Automatic Substation

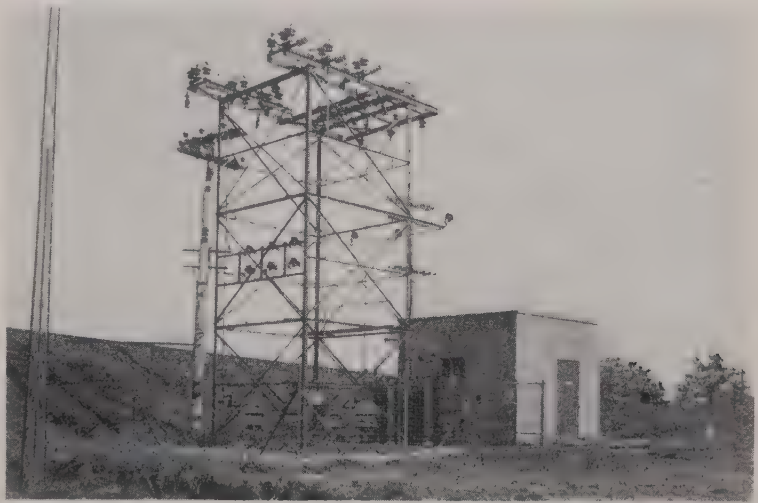


Fig. 8. Farmingdale Automatic Substation

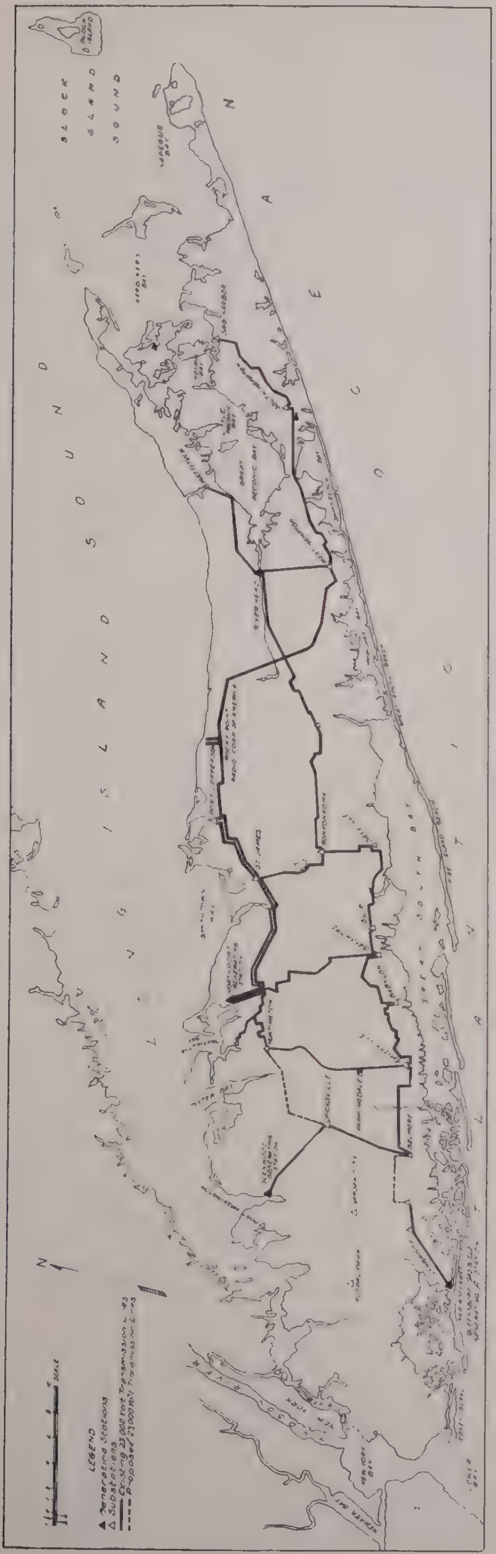


Fig. 9. Map of Long Island, N. Y., showing the location of the Long Island Lighting Company's Generating Stations, Transmission Lines and Substations

Glen Cove
One 600-kv-a., 2300-volt, 3-phase, 60-cycle incoming line
One 400-kv-a., 2200-volt, 2-phase, 60-cycle incoming line
Three 2300-volt, 100-amp., 3-phase outgoing feeders
Two 2200-volt, 100-amp., 2-phase outgoing feeders
Four 2300-volt, 15-amp., single-phase outgoing feeders for street lighting

Mattituck
One 600-kv-a., 13,200/22,800, Y-primary, 2300-volt secondary, 60-cycle, 3-phase incoming line
One 2300-volt, 15-amp., 3-phase outgoing feeder
Two 2300-volt, 75-amp., 3-phase outgoing feeders
One 2300-volt, 10-amp., single-phase outgoing feeder for street lighting

Bellmore
One 600-kv-a., 13,200/22,800-Y, 2300-volt, 3-phase incoming line
Two 2300-volt, 60-amp., 3-phase, outgoing feeders
Five 2300-volt, 15-amp., single-phase outgoing feeders for street lighting

St. James
One 450-kv-a., 13,200/22,800-Y, 2300-volt, 60-cycle, 3-phase, incoming line
Two 2300-volt, 80-amp., 3-phase outgoing feeders
One 2300-volt, 15-amp., single-phase outgoing feeder for street lighting

Huntington
One 1500-kv-a., 13,200/22,800-Y, 2300-volt, 3-phase, 60-cycle incoming line
Three 2300-volt, 100-amp., 3-phase outgoing feeders
One 2300-volt, 125-amp., 3-phase outgoing feeder
One 2300-volt, 25-amp., 3-phase outgoing feeders for street lighting

Islip
One 600-kv-a., 13,200/22,800-Y, 2300-volt, 60-cycle, 3-phase incoming line
Three 2300-volt, 100-amp., 3-phase outgoing feeders

Westhampton
One 450-kv-a., 13,200/22,800-Y, 2300-volt, 60-cycle, 3-phase incoming line
One 2300-volt, 100-amp., 3-phase outgoing feeder

Ronkonkoma
One 450-kv-a., 13,200/22,800-Y, 2300-volt feeder installed in outdoor switch house

Sag Harbor
One 300-kv-a., 2300-volt, 3-phase, 60-cycle outgoing feeder
One 225-kv-a., 2300-volt, 3-phase, 60-cycle outgoing feeder

The automatic substation has undoubtedly minimized the service failures which are always an irritation to central-station customers, and this constitutes a valuable aid in building up the good-will of the public. In this respect it also enhances the public's confidence in the central station and is, therefore, conducive to customer-ownership. It makes available a means of supplying service to outlying districts that could not be reached economically in any other way.

A Survey of the Field for the Electric Truck

By Raymond Zindle

Society for Electrical Development, New York City

Many years ago a fiction writer, with a Jules Verne turn of mind, concocted a fanciful tale dealing with the state of affairs in the year 2000 A.D. Among other things he imagined that all highway transportation would be by means of "electric drays." As to the exact mechanical method to be used he was privileged to be silent. Since then the electric vehicle has arrived and is establishing its sphere of commercial service within which it operates more economically than the horse-drawn vehicle or the gasoline truck. To determine the present status of the situation, Mr. Zindle recently made an extensive investigation and in the following article reports a number of its interesting conclusions—Editor.

It is apparent on all sides that the electric truck industry is entering into an era of unprecedented prosperity and that the electric-driven vehicle is being generally accepted as the most economical, most efficient, and best means of frequent-stop delivery.

Though the electric truck made good its start twenty years ago, it was in those days unfortunately a competitor of the gas truck and was frequently misapplied. Besides this mistake the early electric truck was far from perfect. Today it is a different vehicle. In every feature of construction and equipment, from battery to motor, in every part, including steering gear and frame, there have been many improvements to increase its adaptability. With increased speed, increased mileage per charge, increased flexibility, it is a well built, soundly constructed, efficient, and long-lived vehicle.

For the Society for Electrical Development the writer recently made a field survey to ascertain what users and non-users of electric trucks really think about the vehicle as well as the outlook for its increased use. The inquiry aimed also to get at the frame of mind of central station men and truck dealers in general. After talking with these groups and others in 35 cities, as far south as Atlanta, west to Chicago, and north to Montreal, it appears that the difference between the electric truck situation of today and that of even a year ago is the fact that business men generally are now open minded on the subject of electric truck transportation—that they are willing to face the facts. Business men realize that they must reduce delivery costs; that leaders in every line of industry are using electric trucks where they are applicable in their transportation departments, as a means of reducing these high costs. That the electric truck is inherently the most economical and most efficient means of city transportation within the confines of its proper application is a conviction to be found on all sides. These facts have been pretty well instilled into minds of business men the country over.

Realizing that the provision of battery-charging and other service facilities is of tremendous import in the program of increasing the use of electric trucks the country over, the manufacturers of trucks, batteries, and accessories are joining with the central station industry in an effort to provide these facilities locally throughout the country.

For a long time the central stations of the country were slow to give the electric truck industry their assistance, but today we find them interested in building up an off-peak load and hence ready to co-operate. Because the electric truck is bringing satisfaction to users and because a battery-charging load is the best means of filling up the night valleys in station load curves, the central stations are now helping to promote the use of electric trucks wherever such use seems justified locally. The following central stations report that they are devoting some part of their advertising appropriations to electric truck promotion in addition to personal solicitation and other promotional efforts:

Atlantic City Electric Co., Atlantic City, N. J.
Baltimore Gas & Electric Co., Baltimore, Md.
Blackstone Valley Gas & Electric Co., Pawtucket, R. I.
Commonwealth Edison Co., Chicago, Ill.
Department of Public Service, Los Angeles, Calif.
Lakewood & Coast Electric Co., Lakewood, N. J.
New Orleans Public Service Co., Inc., New Orleans, La.
New York Edison Co., New York, N. Y.
New York & Queens Electric Light & Power Co., Long Island City, N. Y.
Northwestern Electric Co., Portland, Ore.
Pacific Gas & Electric Co., San Francisco, Calif.
Portland Railway, Light & Power Co., Portland, Ore.
Public Service Co. of Colorado, Denver, Colo.
Public Service Electric Co., Newark, N. J.
Public Service Co. of Northern Illinois, Chicago, Ill.
San Joaquin Light & Power Co., Fresno, Calif.
United Illuminating Co., Bridgeport, Conn.

Many others are lending their assistance in co-operating with electric truck salesmen, in lending motor-generator sets to new small users and otherwise offering a helping hand.

Investigation has proved conclusively that in the final analysis users of electric trucks are employing them because of the economies to be realized in their delivery service. Other advantages of the electric—and they are many—are incidental to this outstanding factor. Among them may be mentioned superior dependability, and the fact that the trucks may be allowed to stand at loading platforms overnight, thus doing away with the need for stable or garage space. Many instances were noted where companies now using only a few electric trucks are preparing to replace all of their horse-drawn equipment with this economical means of transportation. The successful use of electric trucks by leaders in industry, such as the American Railway Express Co., Ward Baking Co., National Biscuit Co., etc., has been an outstanding reason why many others have purchased them.

A diversity of individual conditions also has precipitated the use of electric trucks for one economic reason or another. One user reported that he had purchased electric trucks in order to avoid building a stable on very expensive land. Another user installed them solely on the basis of a lower fuel charge. Because he was a large power user, his charging rate amounted to only 1½ cents per kw-hr. (approximately).

The investigation showed that electric trucks are seldom being overloaded although there is a general feeling among users that they will stand greater overloading than any other truck. An ice cream company in Boston, Mass., habitually overloads its electric trucks 50 per cent during the heavy season.

Electric truck routes vary in length from as low as 10 or 12 miles daily up to 35 or 40. The majority of users interviewed report their daily mileage as being from 20 to 30 miles per route.

Delivery stops per route per day range from 30 to 200. Most users report that the average number is between 100 and 200. Some make as many as 250 or 275 delivery stops daily. Garbage collection trucks may make as many as 690 stops per day. In the Chicago loop district one user stated that his trucks encounter an average of four traffic stops per block.

Almost without exception the users report that the charging of truck batteries presents no problem. A few users who charge their trucks at public garages lament the mileage lost in traveling the distance between the company's plant and the charging service point.

The following statements made by users throw an interesting light on the electric truck situation.

> A laundry in Portland, Me., adopted the use of electric trucks to avoid the high costs of maintenance involved in the driving of gas trucks at excessive speeds.
>
> A Cleveland, Ohio, baker expects to eliminate horses entirely and replace them by electric trucks as the company has more capital for investment.
>
> A Pittsburgh, Pa., department store uses both gas and electric and would give up the gas trucks if Pittsburgh were not so hilly.
>
> A Cleveland, Ohio, department store now using a single electric for package delivery will probably add 15 more if the one now in service "goes through the winter OK."

It would appear that transportation analysis is the ideal basis on which to apply electric trucks. In this connection it is interesting to note that the electric truck industry has, within the last year or two, reorganized its selling methods with this end in view. Electric trucks are being sold only where they are applicable. Thoughtful men are taking charge in the truck industry and material changes have been made in selling plans so that now the electric truck is being furthered on an educational basis—the basis of its logical application in city transportation.

The Picking of Managers

By John T. Broderick
Manufacturing Department, General Electric Company

Although of a technical character, this article is of an unusual type in our magazine for instead of dealing in volts, kilowatts, pounds per square inch, etc., it deals in terms of honesty, imagination, personality, etc. It is further unusual in that the position analyzed ranks above those which have ordinarily received such consideration in print. Most of us have little influence in the picking of a manager, but nevertheless will be interested to learn how engineering principles can be applied to the making of a wise choice.—Editor.

Relative Influence of Jobs

Most of the discussions about keeping an organization well manned, so that its vigor and efficiency will not diminish with time, cover a limited field. They do not extend to men filling positions of higher rank than that of a foreman, namely, to superintendents, department heads, and managers.

"What should be the qualifications of a foreman?" is an oft-repeated question, and as far as it goes is a pertinent one. The question, "What should be the qualifications of a manager?" however, is rarely asked, at least openly. Perhaps it serves often enough as a topic of private conversation among subordinate employees; but conclusions arrived at in conversation of that character lack practical value as they cannot be examined, in any definite and concrete form, by men broadly responsible for administrative routine and concerned with the building up of an efficient personnel.

That foremen need to be well equipped for the work they have to do is taken for granted. Their cumulative power for good or evil, in an economic sense, is beyond computation. In considering individual jobs and the qualifications of employees assigned to them, however, range of influence must be dealt with as a primary factor. While it is important that foremen be capable, it is more important that the men of higher rank be so, because the effect of what they do, and what they are, has a wider spread. A misfit in a minor job muddles things at one point. In a big job he can wreck an enterprise.

One Distinction

Let us assume that a foreman, a superintendent, a department head, and a manager should possess certain qualifications in common, such as personality, knowledge, experience, and energy. There are other qualifications, however, which are not indispensable for foremen, and those performing different classes of supervisory service under foremen, but which are indispensable for a manager or any one who gives direction, color, and character to the work of a large number of employees with diversified tasks.

A foreman who, for example, has charge of a machine shop with 50 workers performing repetition labor, may be said to be a high-class foreman, and may, in time, become fitted for a managership if, among the other qualifications that his job as a foreman demands, he has what is known as imagination. The work that he supervises will not suffer seriously, however, or for a long period, if he does not have imagination in large measure. The feature of safety in his case is that his area of influence is limited and that if he is not wholly fitted for the job, which for the time being is his, he may readily be shifted to another for which he is better fitted, or his services may be dispensed with.

A manager, on the other hand, who directly or indirectly supervises the work of a thousand, ten thousand, or twenty thousand employees, must be richly endowed with imagination, in addition to having the qualifications expected of him in common with a foreman. Otherwise, the work that he is chosen to do, even though it may seem satisfactory to a casual observer, is not likely to be done efficiently. In his case limited knowledge and experience will be less hurtful, economically, than a deficient imagination. And, moreover, if he is a misfit, there are usually many reasons why his replacement and assignment to duties of a different character cannot readily be effected.

Imagination Defined

Now, what is meant by imagination? Almost any one will see at once that it is the outstanding qualification of an artist, a dramatist, an inventor, or any one else whose work is creative. So far as it relates to administrative or supervisory duties in industry, imagination may be defined as the power to understand what is not obvious, to balance and co-ordinate a great variety of factors, some of which may be obscure and call for research, to see ahead, as well as on both sides and behind, but particularly to see ahead and to make plans for next month's or next year's work. One of its indications, also, is a readiness to entertain and to try new ideas.

So far as imagination is concerned, a manager therefore should be classed with an artist, a dramatist, and an inventor. If he cannot feel at ease in that kind of company he is not likely to function well as a manager. That does not mean that he must be able to produce pictures or plays, or even to invent labor-saving devices, but rather that he must have, among other things, the vision and power of co-ordination that such work calls for.

Rating of Qualifications

Seven basic qualifications of a manager or any one in line for a managership are given, as follows, in what seems to be the order of their importance:

(1) Intellectual honesty
(2) Imagination
(3) Judgment
(4) Personality
(5) Knowledge
(6) Experience
(7) Energy

Though not heretofore mentioned, intellectual honesty takes its place, naturally, as an assumed qualification at the head of this list for any one who is to be appraised for a managership. No one whose mental processes are crooked instead of straight, however able he may be, can get far in a managerial or supervisory job—much further, in fact, than his title carries him, which is not very far. Those under him will take care of that point if those above him overlook it. Judgment may be classed with imagination, as the latter has been defined, but is listed as a distinct basic qualification in order to emphasize the fact that a manager must have decision and be a doer as well as a seer.

A study of men holding jobs as managers, department heads, or superintendents, and of those who are being trained to fill such jobs in the future, may be made with advantage by determining their relative strength in the qualifications mentioned. This relative strength may be stated in percentages, letting 100 per cent stand for par.

Percentages for three assumed cases are listed in Table I and will be considered to illustrate how comparisons, employed as an aid in the fitting of men to jobs and jobs to men, may readily be made after obtaining reliable and adequate information regarding the qualifications of different individuals. How such information may be made available will be suggested as this analysis is developed.

Intellectual honesty is given 100 per cent in all three cases, as it must be taken for granted that any one who falls short of par in that qualification should not be considered at all for any kind of a managership, as he is bound to be a failure. Workers will often do their best for a leader with some of the attributes of a blockhead, if he is square with the light that he has, but withhold loyalty from one who is shifty, even if brilliant; and of course organic efficiency is never possible without a loyal spirit. The variation in the other six qualifications is normal, and in the study of actual cases it is necessary only to determine the degrees of variation.

TABLE I

Qualifications in Order of Importance	CASE A	CASE B	CASE C
	Par 100%	100%	100%
(1) Intellectual honesty	100	100	100
(2) Imagination	95	70	40
(3) Judgment	85	85	75
(4) Personality	90	90	70
(5) Knowledge	80	85	90
(6) Experience	75	80	90
(7) Energy	65	80	97

A Surface Analysis

Before any weighting of qualifications is attempted, it will be helpful to make a mere surface analysis of the three cases mentioned, with the object of determining offhand their relative fitness for managerial jobs.

Case A would doubtless make the best manager of the three. He is high in imagination, very good in judgment and personality, good in knowledge, fair in experience, and passable in energy. While energy may be a most important qualification in a foreman or assistant foreman, it seems to be the least important in a manager, as it is not so essential that the manager himself be energetic as that the many others whom his imagination influences shall be so. His individual labor, so to speak, cannot be very much greater in volume than that of any one worker in a force of a thousand, but the volume of his induced labor, or that performed by others under his inspiration, must be very great. Cases of highly capable individual workers, with little or no skill however to bring out the best there is in others, will readily occur to any observer, as they are numerous in most organizations. What such workers are likely to do when invested with much power is to keep organic efficiency low without any intention or consciousness of doing so. It should be borne in mind that the kind of energy here referred to is the physical or bustling kind; the contention here, which some may think a bold one, being that it is not a primary qualification for a manager, and when out of proportion to imagination and other qualifications may be distinctly harmful.

Case B would be a fairly efficient manager because, although he has less imagination than *Case A*, his average in the other qualifications is somewhat higher. The differences in his favor in knowledge, experience, and energy are not enough to balance the difference against him in imagination. In trying to determine the rating of particular individuals through an analysis of the different qualifications listed, these qualifications must be weighted, as has been already intimated, and in a weighted tabulation relating to a manager by far the highest number of points ought to be given to imagination. A tabulation with a scale of assumed weights that seem reasonable will be given later.

Case C would be rather mediocre as a manager, because his imagination is poor, only 40 per cent, and his judgment moderate, 75 per cent, but as he is high in knowledge, experience, and energy, and particularly high in energy, he would be able to render useful service in a subordinate capacity where he could be guided by the imagination of *Case A* or *Case B*. Given very much authority, and left to himself, his low imagination and high energy would be the cause of many costly blunders. A superabundance of energy with little imagination leads to lost motion and duplication of effort with belated action sometimes on vital matters.

Appraisal and Classification of Capabilities

In applying the information obtained by a study such as that described, a pension system might be made use of in the shifting of men or in retiring them prior to the eligible age. The main purpose of a pension system, however, is to make provision for old age, and many exceptions to the rules that govern the granting of pensions might defeat that purpose. The fitting of men to jobs and of jobs to men is a distinct problem. Linking it with questions of age, period of service, and pensions might therefore lead to confusion, as well as to abuse and illwill.

Some confusion from this cause may now exist. When, for example, an employee is seen to lack initiative at 55, 60, or 65, the condition is ascribed to advancing age, whereas an analysis might show that he lacked initiative at 30 or 35, that he was not properly fitted to his job at that time and has ever since worked under difficulties, with disadvantage to himself and to his organization. While old age with its infirmities is at some period inevitable, mere statistics relating to that point have to be used with much discrimination. Some employees between the ages of 50 and 70 keep in good physical condition and preserve a youthful spirit. Their experience is a valuable asset and may be made use of fully through a plan under which human capabilities would be appraised and classified.

TABLE II

Case A

Qualifications	WEIGHT UNITS		RATING PER CENT		TOTAL POINTS
Par	100	×	100	=	10,000
Intellectual honesty	(Indispensable, therefore not weighted)				
Imagination	35	×	95	=	3325
Judgment	18	×	85	=	1530
Personality	17	×	90	=	1530
Knowledge	13	×	80	=	1040
Experience	12	×	75	=	900
Energy	5	×	65	=	325
					8650

Per cent of Par 86½

A Plan

The development of such a plan should not be difficult; any more difficult than the development of a system for the classification and appraisal of tools used in production. Employees reveal their qualifications through what they do and the way in which they do it, but it has not been customary to catalogue and index the qualifications of a manager and to determine their relative influence on efficiency with the object of making suitable selections for jobs. It seems reasonable to assume that the quality of administrative work could be improved through its treatment in some such scientific way as that outlined. To be sure, a human being regarded as a mechanism has more variables than other mechanisms, but thorough-going study should lead to any necessary or useful factoring of these variables. It should be remembered that the qualifications listed are basic ones, and that measurements applying to them would have to be modified by collateral qualifications, or the lack of them, as well as by facts as to age, health, and temperament.

One Cause of Misfits

An associate with whom the writer discussed this subject of fitting men to jobs suggested that executive ability be classed as a basic qualification. For the purpose of this article, however, it is not so classed because such ability is the result of a co-ordination of the qualifications mentioned. Treating it as a distinct qualification probably leads to many misfits in management. Executive ability, for example, is popularly associated with energy or motion, and as a consequence an energetic man, or one whose motions are rapid and vigorous, is readily chosen for a job for which he is not wholly fitted because of low or mediocre imagination. In practice, it is much easier to err through the misplacing of energetic men than through the misplacing of those of high imagination. A man who is high in imagination, but very low in energy, as well as in the other qualifications, is apt to be appraised as a day-dreamer, and on that account definite responsibilities are not readily assigned to him. He is left to work in the way in which he can best work.

TABLE III

Case B

Qualifications	Weight Units		Rating Per Cent		Total Points
Par	100	×	100	=	10,000
Intellectual honesty	(Indispensable, therefore not weighted)				
Imagination	35	×	70	=	2450
Judgment	18	×	85	=	1530
Personality	17	×	90	=	1530
Knowledge	13	×	85	=	1105
Experience	12	×	80	=	960
Energy	5	×	80	=	400
					7975
Per cent of Par					79¾

To state the case in another way, there is an automatic check on the mischief that a mere day-dreamer may do; whereas a man with boundless energy, particularly if combined with an engaging personality, but with very little imagination, knowledge, and experience, can do irreparable damage before his limitations are gauged.

The writer recalls a dialogue which he once heard between two loyal employees concerning their superior. "He is dynamic, but lacks vision," said the first employee. "Yes," said the other, "he certainly qualifies on dynamics, but it is a pity that he is not made chief of the mailing department or the yard gang where he could do justice to himself and be of service to the organization." This case was one of an apparent misfit in a managerial job.

Qualifications Weighted

In Tables II, III, and IV, the three cases that have been described are analyzed to determine the fitness of each for a managerial job through a weighting of their qualifications. The rating percentages established earlier for the different classifications in each case are retained; and 10,000 points, fixed as unity, are apportioned to the qualifications according to the importance of the latter.

TABLE IV

Case C

Qualifications	Weight Units		Rating Per Cent		Total Points
Par	100	×	100	=	10,000
Intellectual honesty	(Indispensable, therefore not weighted)				
Imagination	35	×	40	=	1400
Judgment	18	×	75	=	1350
Personality	17	×	70	=	1190
Knowledge	13	×	90	=	1170
Experience	12	×	90	=	1080
Energy	5	×	97	=	485
					6675
Per cent of Par					66¾

It is easy to see that in dealing with actual cases differences of opinion may develop as to ratings and as to the apportionment of weight units to the different qualifications. Some may think that energy, for example, should be ranked higher than seventh and given a greater number of weight points than five; and they may be right. The tabulations are but one expression of judgment concerning the relative influence on organic efficiency of qualifications required in a manager as distinct from men filling other positions. All of the qualifications mentioned are essential. Why energy is placed at the bottom of the list and given the fewest weight units has already been explained in part. No disparagement of that praiseworthy qualification is intended. The fact that *Case A* is only passable in energy unquestionably limits his value in some measure. With imagination of 95 per cent and judgment of 85 per cent, he would be better off with energy of 80 or 90 per cent instead of 65. *Case C* however is different. With rather low imagination and only passable judgment, his energy of 97 per cent would make him a positive menace in a managerial job. Teamwork being the outstanding requirement in an industrial organization, the individual hustler has a mission there only as he works constructively with others and is as eager to promote their efficiency as his own.

In conclusion, the writer wishes to state that his primary intention has been to illustrate the practicability of predicting managerial capacity through the determination and appraisal of the essential qualifications. The problem of personnel is receiving widespread attention, and will be solved largely through the selection of capable managers, because the men at the top give an organization its tone and are the measure of its capacity for service.

Oil-immersed X-ray Generating Outfits and Their Uses

By Dr. W. D. Coolidge
Research Laboratory, General Electric Company

The application of x-rays to medical diagnosis and treatment formerly depended upon apparatus which was both bulky and costly. Its successful operation required elaborate equipment and the services of a trained personnel. Dr. Coolidge, who is the inventor of the tube which bears his name, has now come forward with small, self-contained x-ray outfits which, being portable and easily and safely manipulated without expert technique, can be used in many new applications, in dentistry, in the physics laboratory, and in the industries. In answering the need for simpler and safer x-ray outfits these sets are destined to spread the use of Roentgen's discovery into many new fields. The article we are here presenting is reprinted from the Dec., 1924, issue of the *Journal of the Optical Society of America and Review of Scientific Instruments*.—Editor.

The application of x-rays has almost invariably been attended by the possibility of accidental electric shock to the operator and, in medical applications, to the patient as well. In the early history of the art, when the x-ray tube was excited from a static machine, an induction coil or a high-frequency coil, contact with the high tension circuit ordinarily involved only annoyance and discomfort. With the advent of higher power tubes, operated from transformers, that which had been merely a possible source of annoyance became a real danger. The hazard was still further increased when, for radiographic work, the rheostat in the low tension circuit, used to control the voltage in the high tension circuit, was replaced by an auto-transformer.

The electrical danger could, at any time, have been eliminated by putting the whole high tension system, including the x-ray tube, into an earthed metallic enclosure. This method, however, when applied to the early forms of x-ray apparatus would, in general, have rendered them bulky and mechanically rather inflexible.

With the advent of a self-rectifying x-ray tube, which is stable and can be made very small, it became interesting to mount the x-ray tube inside of the transformer tank and in the same oil with the transformer, making the latter as small as possible. In another paper(1) the writer has described his earlier work in this field. The following is a description of two experimental outfits of the oil-immersed type, which have been more recently developed. They were both intended primarily for medical diagnostic work. Laboratory experience with these outfits shows that they should also have many other fields of usefulness. They lend themselves especially well to physical demonstrations and, in general, to cases where x-rays are desired for short periods of time.

Owing to the enclosure of the whole high tension system in a grounded metal container, there is with this system no external electrostatic field. This eliminates the danger of electric shock and is an advantage in some experimental work where the effect of x-rays might otherwise be masked by the presence of the electrostatic field of the high tension system. This type of apparatus also permits a very close approach to the focal spot and, hence, to a region of strong x-ray intensity. Other advantages are to be found in the mechanical ruggedness of the apparatus and in the simplicity of its operation.

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(1) *Am. Jour. of Roentgenology*, 7, pp. 181-189, 1920.

Dental Outfit

The small outfit described in this section was developed primarily for the use of the dentist for intraoral radiography.

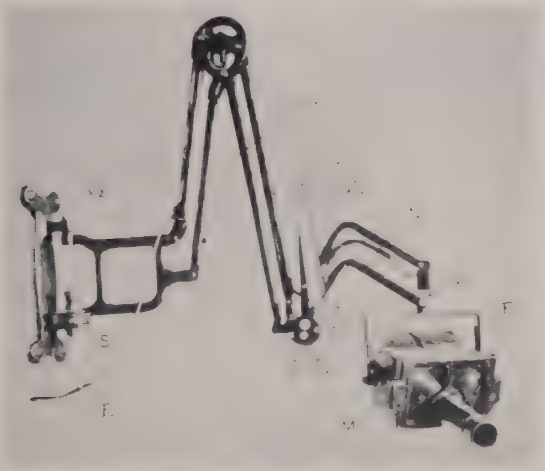

Fig. 1. Dental Unit Mounted on Wall Bracket

In its mechanical design the aim has been to attain the following ends:

(1) To enable the operator to follow his visual inspections by a radiograph without in any way changing the position of the patient.
(2) Easy and smooth mechanical operation of the outfit.
(3) Easy and complete removal of the outfit, when not in use, from the neighborhood of the patient.
(4) The occupation of as little floor space as possible.

On the electrical side, attention has been given to:

(1) Electrical protection from both the high tension and low tension circuits.
(2) Minimizing the effect of line voltage fluctuations by the use of a stabilizer which holds the milliamperage constant.

The attractiveness of the system is very largely dependent upon the degree of perfection attained in the mechanical and electrical design. This is due mainly to the following considerations:

To move the source of rays, it is necessary with this system to move the whole x-ray generating outfit, which is, of course, heavier than a simple x-ray tube and protective shield. To make such movement easy and smooth, and this is very desirable for work about the face, friction must be reduced to a minimum. To this end, the weight of the generating outfit must be reduced to a minimum. Light weight is desirable for two other reasons. Even if there were no friction, there is the inertia of the mass to be overcome in putting the outfit in motion or in stopping it. Furthermore, the weight has to be carried, in some positions, at a distance of several feet from the supporting wall or column and this calls for a very strong support, unless the weight is kept small.

Because of the diminished accessibility of its parts, such an outfit, to be desirable, must operate faultlessly for long periods of time.

General Description

The dental outfit is shown in Fig. 1 and consists of an x-ray generating unit which is completely enclosed in the grounded metallic container, *M*, and is mounted on pivots in a rotatable fork, *F*, attached to a special wall bracket. This mounting permits the unit to be pointed in any direction, raised and lowered and brought to any point within quite a large space. Through accurate balancing of parts and the use of friction devices, the movement of the unit is made easy and smooth and it stays wherever it is put without the use of clamping devices. Low tension is led to the transformer by means of the single conductor insulated cable *E* passing through metal conduits. The grounded metal bracket itself is used for the return circuit. At no point is the live side of even the low tension circuit exposed. The x-ray tube operates at 10 milliamperes and 56,000 volts (max.), and the time factor is automatically controlled by means of a small time-switch, not shown in the illustration.

The X-ray Generating Unit

The x-ray generating unit is shown in length section in Fig. 2 and in end section in Fig. 3.

The small x-ray tube, *X*, is seen mounted close to the high tension coils C_1 and C_2 of the 56,000-volt (max.) transformer. The low tension coil, not shown, is on the same leg of the magnetic circuit as the high tension coils and is inside of the latter. *T* is the separate filament transformer, *M* the metal tank and *B* the bakelite cover. B_1 is a false cover of aluminum which supports the bakelite cylindrical tubes Q_1 and Q_2 which serve to establish mechanical contact with the patient.

Z is a sheet of $\frac{1}{32}$-inch lead and D is a tapering tube of the same material for the x-ray protection of the operator.

Fig. 4 is a length view showing a cross section of the oil expansion chamber G and the Kearsley stabilizer J together with the resistance unit R, which is automatically cut in and out of the filament circuit by the stabilizer. W is a cover, here shown raised, but ordinarily closed, to protect the stabilizer and resistance unit.

The Support Mechanism

The x-ray unit, which weighs 20 pounds, is rotatably so mounted in a steel fork that the axis of rotation passes through the center of gravity of the unit. The fork is itself rotatable about its vertical axis, V_1, Fig. 1. A link mechanism, N, permits of raising or lowering the unit through a distance of 14 in. Freedom of motion in an essentially horizontal plane is permitted by an S. S. White dental bracket, V (here used in an inverted position). The whole supporting arm is made rotatable about a vertical axis, V_2.

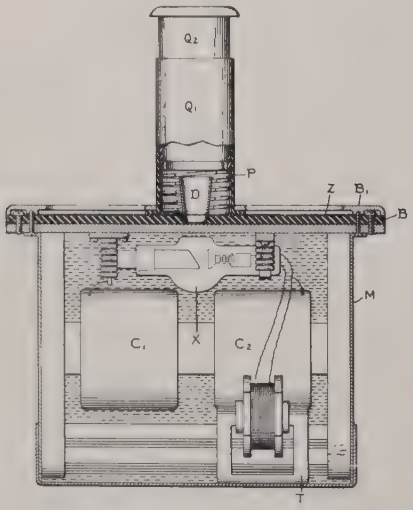

Fig. 2. Length Section of Dental Unit

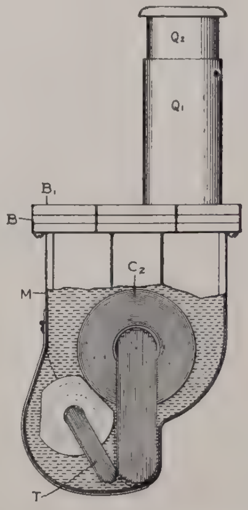

Fig. 3. End Section of Dental Unit

So far as its vertical motion is concerned, the weight of the unit is accurately balanced in all positions by a pair of spiral springs (inside of the tubular spring-housings), Z_1 and Z_2 and steel cables, K_1 and K_2, passing over specially designed cams, O_1 and O_2. For the purpose of maintaining this balance in the face of changes which may take place in the springs, the tension of the latter is made adjustable.

The design of the dental arm is such that the 20-pound unit is nearly in equilibrium in the horizontal plane.

Through the inherent friction and through the use of friction discs the unit will stay wherever it is put in space.

The bracket may be carried from the wall, as in Fig. 1, from a special column, or from some existing dental fixture.

Relative immobility of x-ray tube and patient is secured by the following artifice: A cylindrical tube of bakelite or other material, Q_1, Fig. 2, is rigidly attached to the cover of the x-ray unit. A second tube, Q_2, with an easy sliding fit inside the first one and with a travel of about 1 in. is urged outward by a weak spiral spring, P. The inner tube, moving freely in its sheath, maintains mechanical contact between the x-ray outfit and the patient. The spring under the movable tube controls the contact pressure and must not be too strong as otherwise it will cause discomfort to the patient. On the other hand, it must not be too weak as otherwise it will not be sufficiently effective. The effect of the contact tube is to hinder relative motion of x-ray outfit and patient in any other direction than the one which is least harmful to the resulting radiograph. Even in this direction also it is quite effective owing to the friction between tube and sheath.

The spring behind the contact tube tends to push the x-ray outfit away from the patient. Such motion, if allowed to take place, would defeat the purpose of the contact tube, and is prevented by the use of a friction device, *S*, in Fig. 1.

The X-ray Transformer

The small x-ray transformer is the result of a good deal of experimental work. The following are some of the considerations affecting its design:

The smaller the cross-section of the iron core, the greater is the number of turns required in the primary and secondary coils. Reduction of iron beyond a certain point will then lead to an increase rather than a decrease in the diameter of the high voltage coils. Furthermore, the effect of the increase in the number of turns will be to increase the resistance of the coils and this, for use on a self-rectifying tube, will, for a given "useful" voltage, increase the "inverse." It will be the higher of the two voltages, the inverse, which will determine the insulation required for the high voltage coils. The increased "inverse" will then necessitate larger secondary coils with more spacing between them and a larger container.

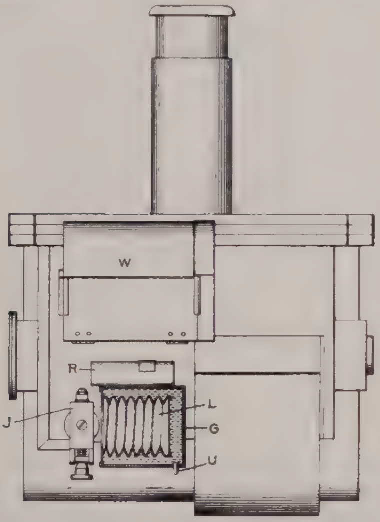

Fig. 4. Length View of Dental Unit, with Oil Expansion Chamber, G, Stabilizer, J, and Resistance, R, Uncovered

A reduction in the diameter of the copper wire used in the coils will increase resistance and hence increase "inverse." Beyond a certain point, then, a decrease in the diameter of wire will be attended by an increase in the size of the container.

There will be a compromise design which will lead to the smallest and lightest weight outfit.

The Tube

Fig. 5 gives a half-size view of the tube, and Fig. 6 an enlarged cross-sectional view of the cathode. With the small focusing device, the focal spot would be too small were it not for the molybdenum pin which projects through the center of the filament spiral.

The tube operates, in oil, at 56,000 volts (max.) and 10 ma. The bulb of this tube, the stippled portion in Fig. 5, is made of glass containing 55 per cent by weight of the element lead. The wall-thickness is ⅛ inch. The protection offered by the lead glass envelope is equal to that of $\frac{1}{32}$ inch of sheet lead. The window through which the x-rays emerge is made of thin walled, lead-free, lime glass. The focal spot is ⅛ inch in diameter. The angle of the toe of the target has, in this tube, been made 60 deg. instead of the usual 45 deg., for the following reason: If, through overload or any other cause, the tube should allow any "inverse" current to pass, it is desirable that this "inverse," which comes from the focal spot in a direction normal to the working face of the target, should be intercepted by the molybdenum focusing device. It would otherwise impinge upon the glass wall of the tube and probably crack this by local heating. The use of the larger target angle brings the normal to the target face nearer to the tube axis and hence permits of the use of a smaller focusing device than would otherwise be necessary. This is important in this case where it is so desirable to make the tube small.

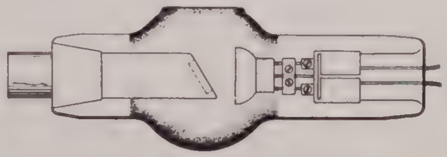

Fig. 5. Dental Tube (one-half size)

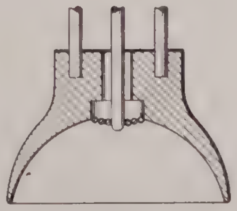

Fig. 6. Enlarged Cross Section of Cathode of Dental Tube

The cathode filament spiral calls for a heating current of 2.2 amp. at 2.6 volts. The low filament wattage involved permits of the use of a very small filament transformer.

Oil Expansion Chamber

As a result of the low efficiency of x-ray production and the location of the x-ray tube in the oil with the transformer, all but a negligible amount (less than one-tenth of one per cent) of the electrical energy delivered to the transformer appears finally in the oil as heat.

The tank and other metal parts expand relatively little but the oil expands considerably on heating.

For the device to be operable in all positions, it is necessary, for the insulation of the high tension system, that the tank shall at all times be full of oil.

As the tank is made of thin metal and as it must be maintained perfectly oil-tight, it is not permissible for the oil-pressure within the tank to rise to more than 5 or 10 pounds above that of the atmosphere.

In the present outfit, the expanding oil flows out from the tank through the tube *U* (Fig. 4) into the cylindrical chamber *G*, in which there is an accordion-shaped metal tube, *L* (a piece of "sylphon" tubing), closed at the inner (right-hand) end, which collapses as oil flows into the expansion chamber.

The advantages in this type of expansion chamber over that formerly used(2) are that it reduces the bulk of the apparatus and reduces the pressure within the tank.

The Stabilizer

A small Kearsley stabilizer,(3) *J*, Fig. 4, mounted on the outside of the unit, serves to hold the milliamperage constant at the predetermined value. The mode of operation of the stabilizer is seen by referring to the diagram, Fig. 7. The high tension current which passes through the x-ray tube is made to pass through the magnet coil, *H*, of the stabilizer. The magnet coil operates an armature, *I*, which carries one of a pair of co-operating contacts, D_1 and D_2. Through the operation of the stabilizer, the resistance, *R*, is cut in and out of the primary circuit of the filament transformer. By automatically controlling the fraction of the time that this resistance is in the filament supply circuit, the stabilizer maintains, in spite of line voltage changes and in spite of changes which may take place within the x-ray tube, a constant current through the latter. Owing to the fact that the energy required in the filament heating circuit is so small, only about 6 watts, the sparking at the stabilizer contacts is very slight, a fact which makes it possible to operate the outfit a great many times before it becomes necessary to change the adjustment of the stabilizer.

X-ray Protection

As has been pointed out, the lead-glass wall of the x-ray tube is equivalent in protecting power to $\frac{1}{32}$ inch of sheet lead. Further protection might be unnecessary were it not for the following fact: The inner walls of the tube are so close to the focal spot and, hence, exposed to such a high x-ray intensity that they serve as a very strong source of secondary rays and these escape under a wide angle through the transparent window. To suppress them, a sheet of lead $\frac{1}{32}$ inch thick, *Z* in Fig. 2, and the lead cone, *D*, are used.

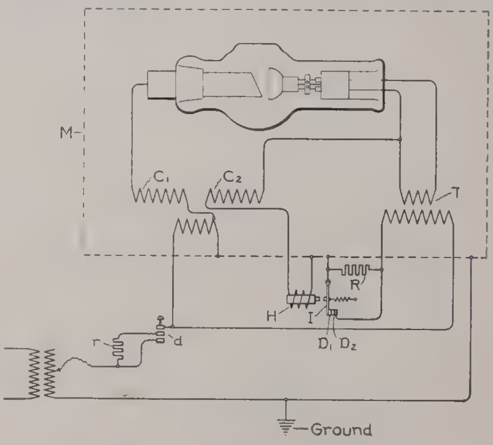

Fig. 7. Diagram of Connections

The Low Tension Circuit

Only one wire is used for the low tension circuit, the supporting arm itself serving as the return conductor. With this system, but two sliding contacts are required, one at the upper end of the fork which supports the unit and the other at one of the lower ends of the fork.

The circuit diagram is given in Fig. 7, in which the letters have the same significance as in the preceding illustrations.

Current is supplied to the unit from a 1 to 1 transformer provided with several taps. The coil of this transformer which delivers current to the x-ray transformer has one end connected to earth and to the metal support arm and the other end to the insulated cable. The function of this auxiliary transformer is two-fold. Its use makes it safe to apply the ground as shown, and, through the choice of the proper tap, it adapts the line voltage to the unit.

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(2) *Am. Jour. of Roentgenology*, 7, No. 4, pp. 181-189, April, 1920.

(3) W. J. Kearsley, Jr., *Jour. of Radiology*, pp. 3-7, July, 1921.

The Operating Switch

The operating switch, *d* (Fig. 7), first closes the low tension circuit through the resistance, *r*, and upon being depressed further short circuits this resistance. The use of the resistance point in the switch prevents the high voltage surge which would otherwise take place whenever the circuit is closed on the peak of a wave.

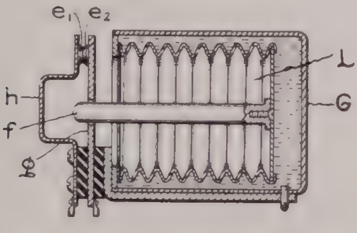

Fig. 8. Safety Device for Dental Unit

Electrical Characteristics

The electrical characteristics of one of the units are given in Table I, in which the first and second columns give the primary voltage and current respectively, delivered to the x-ray transformer from an auto-transformer with variable taps. The third column gives the milliamperage flowing through the tube. The fourth and fifth columns give the peak voltage, "useful" and "inverse" respectively, determined by the use of a sphere-gap and kenotron. The normal operating "useful" voltage for this outfit is 56 kilovolts, at which point the "inverse" voltage is seen to be only 7.5 per cent higher than the "useful."

To operate from a direct-current supply, a rotary converter has to be used, and care has to be taken in its design to prevent its causing too large an increase in the "inverse" high tension voltage.

The filament heating current is 2.2 amperes at 2.6 volts.

Capabilities and Limitations of the Small Unit

To study the effect of mechanical vibration, one of the small units was placed in a close-fitting wooden box and carried about on the floor of an automobile for several weeks of rough winter driving. The mileage involved was small, but twice a day the outfit was taken from the car to the house or laboratory and was, on each occasion, dropped from some little height to the floor. The wiring in this particular outfit had been so arranged that a milliamperemeter could be connected in, and at least once a day the milliamperage was measured. Although the abuse seemed as severe as the wooden box would stand, no damage was done to the unit and the adjustment of the stabilizer remained unchanged, as was shown by the fact that the milliamperage remained constant.

This small unit was intended for diagnostic work only. Even in this field, however, there is a perfectly definite limit to what can be done with it as it stands.

TABLE I

Prim. Volts	Prim. Amp.	Tube Current (Milli-amperes)	KILOVOLTS (MAX.)	
			Useful	Inverse
104.0	4.7	0	. . .	56.0
86.5	8.5	10	42.0	48.3
92.0	8.7	10	45.5	51.8
97.5	9.2	10	48.3	54.6
103.0	9.7	10	52.5	57.5
105.0	10.0	10	54.7	58.8
109.0	10.7	10	56.0	60.2
114.5	12.3	10	58.9	63.1
119.5	14.3	10	61.6	66.5

In one experiment, a current of 10 ma. at 63,000 volts (max.) was thrown on for 5-second periods with 20-second intervals of rest. At the end of 45 minutes the temperature of the oil in the can had risen to 62 deg. Centigrade and the pressure, shown by an attached gauge, had risen from 0 to 10 pounds above that of the atmosphere. While it would not have been safe to go much higher with either the temperature or pressure, no harm had been done to the outfit. This service was equivalent to making 108 intraoral dental radiographs in 45 minutes on slow film. It would not have been safe to continue at this rate as temperature equilibrium had not been reached.

Other experiments indicate that it would be conservative to use the unit continuously for 40 such dental radiographs per hour on "slow" film or about 200 per hour on "fast" film. This latter figure is probably a higher speed than could be maintained by any operator.

That the life of such an outfit, working within its limitations, should be very long was indicated by an experiment in which an outfit was operated from a motor-driven switch, at 10 ma. and 56,000 volts, on a schedule of 5 seconds on and 65 seconds off, 109,000 times. There was no evidence of the tube having been changed in any way by the experiment.

Six of these experimental outfits have now been in use in dental offices for over two years and during this time only one tube has given trouble.

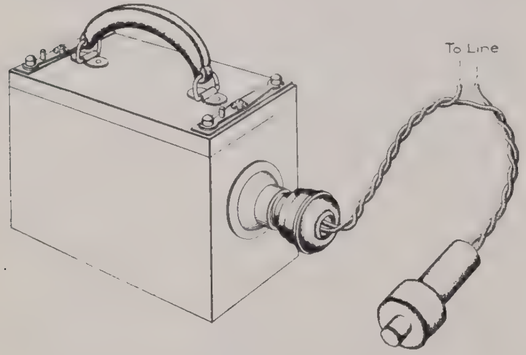

Fig. 9. Dental Unit in Portable Form

Where it is desirable to use the outfit for such hard service that it might otherwise become overheated, the safety device shown in Fig. 8 can be added. The oil expansion chamber, G, is that of Fig. 4 and the safety device consists of a pair of contacts e_1 and e_2 in series with the low tension circuit of the x-ray transformer. As the outfit heats up, oil flows into the chamber *G* compressing the sylphon, *L*. The closed end of the sylphon carries a bakelite rod, *f*, which passes loosely through the contact-carrying member *g*. When the maximum allowable temperature has been reached, the rod, *f*, presses against the other contact carrying member, *h*, and so opens the primary circuit of the x-ray transformer, keeping it open until the temperature of the outfit has fallen to a point where it can be again operated with safety.

If, for any purpose, the outfit is generally to be used in such a position that the tube stands uppermost in the tank above the transformer, the energy which can be continuously dissipated from the tank can be considerably increased by making the tank of copper or aluminum, instead of iron, and making it thick enough so that it will have an essentially uniform temperature throughout. If, on the other hand, the tank is made of thin sheet iron, then only the oil in the neighborhood of the anode and above it will be hot and, because of this fact and the low heat conductivity of the thin iron, only the upper portion of the tank will be very effective as a heat radiator.

Other Applications of the Oil-immersed Dental Unit

As a Portable Device

In its simplest and most portable form, the unit is shown in Fig. 9, mounted in a wooden box which is provided with a removable cover which carries a suitable handle.

The small resistance unit, *r*, of Fig. 7, is included in the handle of the push-button switch.

In this form the unit can be used for bedside radiography.

It seems especially well adapted to use in the surgical operating room for fluoroscopic control in connection with the removal of kidney stones, that is, in those cases where the kidney is, for this purpose, delivered through the wound.

Such an outfit might render useful service to the building-contractor for the fluoroscopic examination of walls and ceilings for getting information concerning the location of concealed timbers, wires, pipes, etc.

In this form the unit should find many uses in industrial research where it can be employed for easy radiographic or fluoroscopic work, to differentiate between substances which do and those which do not fluoresce under the influence of x-rays, to ionize gases, to dissipate electric charges on the surface of non-conductors, or with the help of an electric field to give to the surface of either a conductor or an insulator an electric charge of either sign.

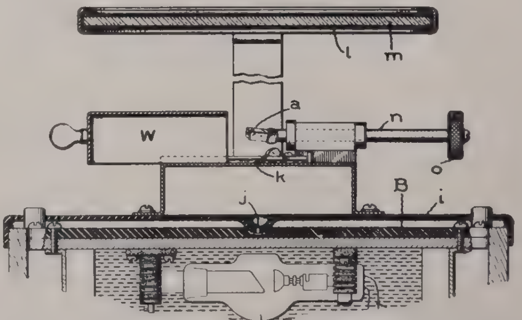

Fig. 10. Vertical Section of Unit Equipped for Fluoroscopic Demonstration of Laue Diffraction Experiment

For Physical Demonstrations

The following illustrations will serve to show the usefulness of the device in physical demonstrations.

Diffraction of X-rays

With the device arranged as in Figs. 10 and 11, the Laue experiment can be shown fluoroscopically. For this set-up, the cover of the outfit, shown in Fig. 9, has been replaced by a metal plate, *i*, in the small depressed portion of which is an opening, *j*, 0.067 in. in diameter. This diaphragm, together with a second one, *k*, having an opening of the same size and mounted 1⅜ in. above the first, serves to define a small beam of x-rays which passes upward to the fluorescent screen, *l*.⁽⁴⁾ The observer is protected by the lead glass, *m*.

With the apparatus as shown, a rock-salt crystal, *a*, cemented to the end of a rotatable shaft, *n*, is in the path of the x-ray beam. As the rock-salt crystal is rotated (by means of the knurled head, *o*) the diffraction pattern, seen on the fluorescent screen, shifts, while the primary beam remains fixed in position.

The plate on which the rotatable rock-salt crystal is mounted is pivoted on a vertical axis, *p*, and carries two other crystal fragments, one of sapphire at *q* and one of diamond at *s*. The dotted position shows the crystal *s* in the path of the x-rays, and a position intermediate between the solid and dotted positions brings the crystal *q* into the beam.

Through the agency of a spring actuated pawl, *t*, and two stops, *u* and *v*, the crystal carrying member is given four definite positions, one for each of the three crystals and one in which there is nothing interposed in the path of the rays.

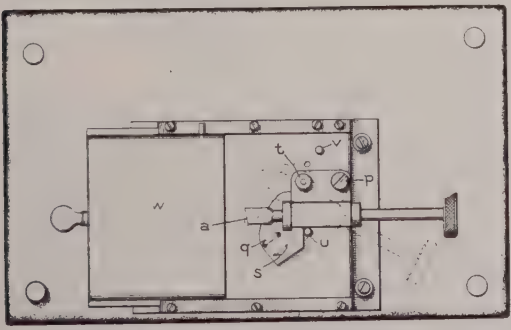

Fig. 11. Plan View Corresponding to Fig. 10

W is a metal cover which can be slid over the crystal carrying member, when the outfit is not in use, for mechanical protection.

Ray-track Experiment

For use with the C. T. R. Wilson apparatus, as modified by Shimizu,⁽⁵⁾ the x-ray unit is provided with a special metal cover carrying two diaphragms and is so placed (see Fig. 12) that the small x-ray beam defined by these diaphragms passes about an inch to one side of the expansion chamber, *y*. A circular window, *z*, of aluminum foil, 0.0025 in. thick and ⅜ in. in diameter, is clamped at the periphery between two brass rings and these are fastened with Khotinsky cement in a hole drilled in the glass side-wall of the expansion chamber.

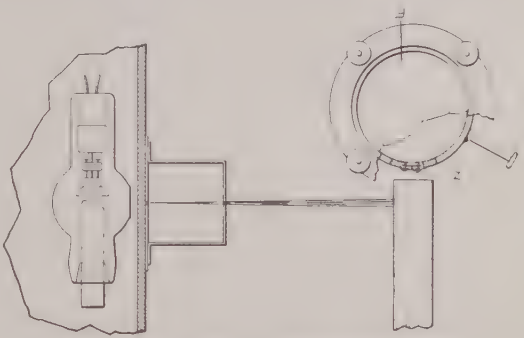

Fig. 12. Plan View of Unit Arranged to show X-ray Scattering by Means of Ray Track Apparatus

When the x-ray switch is closed, no clouds are seen in the chamber unless some source of secondary rays is interposed in the x-ray beam opposite the aluminum window, in which case scattered radiation can enter the expansion chamber.

When a piece of wood is used as the scattering agent, the clouds in the ray-track apparatus appear to have an average length of perhaps a cm., while if copper is used, most of the clouds appear to be only perhaps 2 mm. long. The difference is very apparent and the short clouds are due to the *K*-radiation from the copper.

The Millikan Oil-drop Experiment and a Working Model of It

In Fig. 13 an x-ray unit is shown in the center with the Millikan oil-drop apparatus to the right and the model to the left.

The oil-drop apparatus is essentially as described by Millikan.⁽⁶⁾ A second, demonstration, eye-piece has been added to the telescope. The second observer uses the eye-piece *a* while the demonstrator uses the other eye-piece, *b*.

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(4) The most sensitive fluorescent screen available should be used for this purpose. That made by the Patterson Screen Company, of Towanda, Pa., has been found very satisfactory.

(5) T. Shimizu, *Roy. Soc. Proc. 99*, pp. 425-431; Aug. 2, 1921.

Pressure on *E* uncovers the hole in the upper plate *d*. Compressed air is admitted to the atomizer *g*, through a valve which is not shown.

The self-feeding arc-lamp, *L*, is placed in a light-tight housing, provided with ventilating louvres.

The room is effectively darkened.

High-voltage direct current is obtained from a transformer, not shown, and a kenotron, *K*. A high-resistance unit shown to the left of the kenotron is used to limit the current which can be drawn from the transformer in case the operator makes accidental contact with the high-tension circuit. A second high-resistance unit, connected between the kenotron and ground, allows the voltage of the high-tension circuit to drop as resistance is inserted in the primary circuit of the transformer.

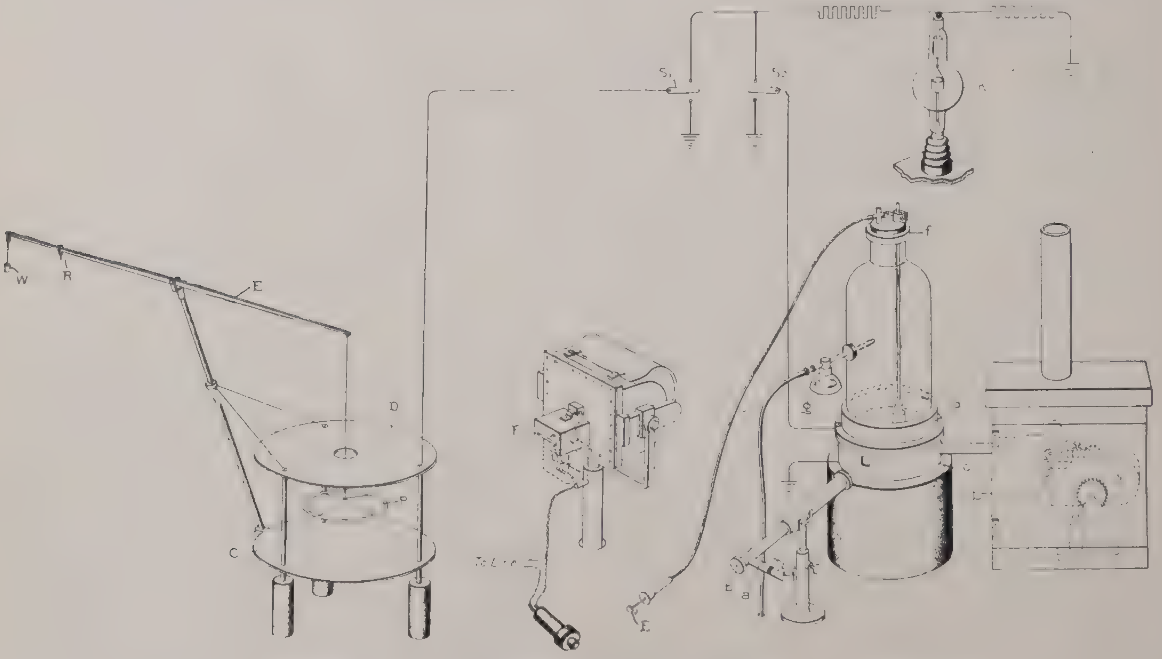

Fig. 13. Perspective View of Unit Arranged to Demonstrate Millikan Oil-drop Experiment and to Operate a Working Model of It

The x-ray outfit is carried by a vertical rod which passes through the top of the table and is counter-weighted so that it can be easily raised and lowered. It is also easily rotatable about the vertical axis.

No attempt has been made to do quantitative work with this apparatus, but it has been used with great satisfaction for showing the qualitative side of the Millikan experiment.

The working model of the experiment is seen to the left of the x-ray outfit in Fig. 13. The large metal plates, *C* and *D*, correspond to the plates *c* and *d* of the Millikan apparatus. *C* is, like *c*, connected to ground while, by means of S_1 and S_2, the high tension current can be switched from *d* to *D*.

The high tension voltage is regulated by means of a rheostat which is connected in series with the primary of the high tension transformer.

The disc of paper, *P*, corresponds to the oil-drop and is hung by a piece of light oiled silk fish line from one end of the light wooden scalebeam, *E*. The paper disc is roughly balanced by the counterweight, *W*, and brought to approximately the midway position between the two plates by means of the rider, *R*.

The experiments may be carried out as follows: Plate *D* is brought to +10,000 volts. If this does not disturb *P*, it shows that *P* is uncharged.

If now, leaving *D* charged to +10,000 volts, a thin beam of x-rays, defined by the rectangular slit in the diaphragm *F*, is passed through the air below *P*, the latter quickly rises showing that it has acquired a negative charge.

(e) R. A. Millikan, *Phys. Rev.* ***32***, pp. 349-397; 1911.

If the voltage of *D* is reduced to zero, *P* returns to its original position, moving upward again, however, if *D* is again brought to +10,000 volts.

The negative charge may next be removed from *P* by bringing *D* to zero potential and then, with diaphragm *F* dropped down, as shown in the dotted position, turning a large beam of x-rays on *P* and the surrounding air.

That the charge has been removed is shown by the fact that upon now bringing *D* to +10,000 volts *P* does not move.

If now using the rectangular diaphragm, and with *D* at +10,000 volts, a thin beam of x-rays is passed through the air above *P*, it is seen that *P* moves downward, showing that it has acquired a positive charge.

The behavior of the piece of paper is then like that of the oil-drop. It can, at will, be made to either acquire or lose electrons.

The experiment also has this to recommend it that, unlike many static experiments, it works as well in wet as it does in dry weather.

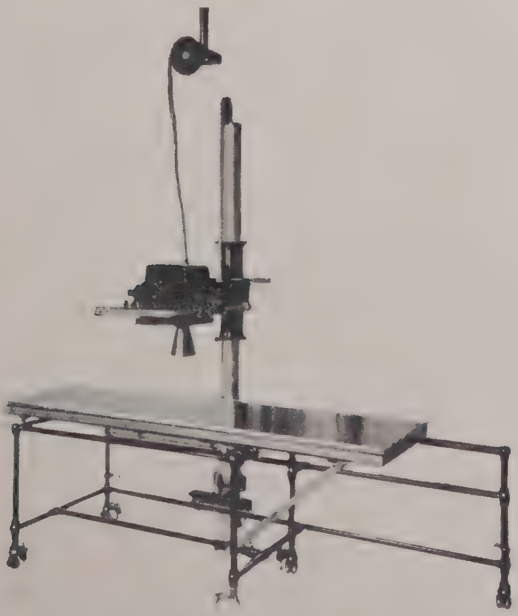

Fig. 14. High Power Oil-immersed Outfit as Arranged for General Medical Radiography

Thermoluminescence

If a piece of fused quartz is held for a couple of seconds in the x-ray beam close to the window of the unit, and is then subsequently heated in the dark in the flame from a Bunsen burner, it is seen that, long before becoming visibly red, the quartz gives off a bright blue light.

If a strip of the ordinary calcium-tungstate intensifying screen, say an inch wide, is held with a pair of tongs in the x-ray beam close to the window of the x-ray outfit, one sees, in a darkened room, a brilliant blue luminescence. Upon removing the screen from the x-rays, one sees that there is but little phosphorescence. If now the screen is brought to liquid air temperature, by immersing it for a moment in a Dewar flask filled with liquid air, and then quickly placed in the x-ray beam for a few seconds, one notices, upon removing it from the beam, first a slight phosphorescence and then, as the screen warms up, a brilliant yellowish green thermoluminescence.

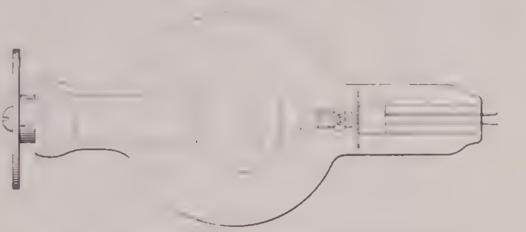

Fig. 15. Tube Used in High Power Outfit of Fig. 14
(One-quarter size)

The experiment is much more beautiful if a barium-platino-cyanide screen is used. In this case the screen gives off green light under the influence of the x-rays and shows very little phosphorescence. If immersed in liquid air and then quickly subjected for a few seconds to x-rays it shows, upon warming up, six distinct thermoluminescent periods taking place in the following order:

Green
Light yellowish green
Reddish brown
Light green
Light reddish brown
Dark reddish brown.

Experimental Oil-immersed Outfit for General Medical Diagnostic Work

This outfit is very similar to the dental outfit already described but differs from it in enough respects to warrant a brief description.

It is designed to operate at 30 milliamperes and 84,000 volts (max.).

The x-ray generating unit, consisting of high voltage transformer, filament transformer, x-ray tube, metal container and oil, weighs 90 pounds.

The unit is shown in Fig. 14 mounted on a regular radiographic table.(7) To house the heavy counterweight, the supporting steel tube is made very large—5 in. in external diameter.

By accurate counterweighting and the use of ball bearings throughout and by arranging to have the two horizontal axes, about which the unit rotates, pass through its center of gravity, the movement of the unit at any point within its range is made easy and smooth.

The connections inside the unit are the same as in the dental unit. The outside connections are so changed that the x-ray switch controls only the current supply to the x-ray transformer. A separate switch controls the current supplied to the filament transformer.

The control stand contains the usual autotransformer, voltmeter, time-switch, milliamperemeter and adjustable Kearsley stabilizer.

A flexible four-wire low tension cable, leading from the unit, is carried on a large spring-reel supported either from the ceiling or from a fixed mast attached to the table. Contact between the wires of the flexible cable and the stationary wires leading away from the reel is secured through brushes and slip-rings.

The x-ray tube is shown in Fig. 15. It is designed to operate at 30 milliamperes and 84,000 volts (max.), and to have a much larger factor of safety than the regular 30 milliampere Radiator tube. The bulb is $3\frac{3}{4}$ inches in diameter and the overall length of the tube is $8\frac{1}{2}$ inches. The anode head is made large and hemispherical in shape and, to permit of more rapid heat flow to the oil, the anode stem is made very large—$\frac{13}{16}$ inches in diameter. To increase that portion of the anode surface which is in contact with the oil, a circular disc of copper $2\frac{1}{2}$ inches in diameter is soldered to the outer end of the anode stem.

X-ray protection is obtained by the use of lead on the outside of the metal tank containing the unit.

This outfit, because of the larger external surface of the container, is capable of continuously radiating more energy than the dental outfit. It is intended, however, for medical diagnostic work and any heavier duty than this would call for water or forced air cooling.

It is a pleasure to acknowledge the able assistance, in this work, of Mr. George Hotaling and Mr. Leonard Dempster.

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(7) A special table of heavier construction would be much better for this purpose.

Studies in the Projection of Light

PART XVI

THE HYPERBOLOID WITH A POINT SOURCE OF LIGHT

By Frank Benford

Physicist, Illuminating Engineering Laboratory, General Electric Company

A reflector or mirror that gives a broad beam is widely employed in floodlighting, and there are several methods of securing a beam that is wide and at the same time definitely defined. The hyperboloid gives a beam that may be given any desired width by a proper design, and as the author points out in this installment, the beam formation is more under the control of the designer than is the case with the paraboloid. The two reflectors are in many respects exact opposites in their optical actions and the rules for one do not apply to the other. The testing conditions are greatly simplified through the fact that the light from a hyperboloid seems to come from an image whose intensity in any given direction is constant and independent of the distance. The analysis of the hyperbolic beam is thus a matter of the greatest directness and simplicity.—Editor.

Optical Action of the Hyperboloid

The hyperboloid is the third of the trio of conics and, with an exception to be noted later, it completes the list of elementary optical actions. The ellipsoid converges the light upon a real focal point, the paraboloid renders the light parallel, and the hyperboloid diverges it so that it radiates from a virtual image point. It is a matter of common experience that the beam from a parabolic mirror can be spread by moving the lamp away from the focus, but there is a sharp limit to the width of the solid beam that may be thus gained. In contrast to this limitation the width of the hyperbolic beam may be made anything we choose by a proper design, but there is one and only one normal beam width from a given reflector, with a certain small amount of adjustment. In some types of illumination a wide beam is desired and here the hyperboloid finds its application.

Each type of reflector has its own characteristic beam formation, but by changes, or rather selections, in the elements of the design, the beam may be altered to any extent. The parabolic beam is the most inflexible, coming as it does from a surface which is always the same and which can vary only in its size and degree of completeness. On the contrary, an infinite number of differently shaped hyperbolas are possible, and there is accordingly an infinite number of hyperbolic beams at our command. They are limited on one hand by the parallel beam from the paraboloid, and on the other hand by the uniformly reflected light from the plane mirror. The choice here is wide, but in one sense the limits to what we may attain have been broadened, not removed, since certain features of the beam are rigidly fixed and the study of these limits is an essential preliminary to the design of a hyperboloidal mirror.

The hyperboloidal mirror is selected for use because it spreads the light in a certain definite manner, and we have one peculiar choice offered us. The hyperbola has an internal focal point and a conjugate or external focal point. A light placed at the internal point will give a beam of less than 180 deg. in width; placed at the external focus the beam will exceed 180 deg. by the exact amount the other fell short, so that the two beams will cover a complete 360 deg. This relation holds providing one branch of the hyperbola is complete, otherwise the sum of the two beams will fall short of 360 deg. The interior focal point gives us the familiar concave hyperboloid, but the convex hyperboloid is also deserving of notice although the "beam" is weaker and more scattered than the direct radiation from the source.

In the exploration of the parabolic beam there was found a wide region in the center of the beam, the inverse-square region, to which all points of the mirror contributed light. Minor defects in the mirror would have minor effects on this region, but in the hyperboloidal mirror the case is otherwise. Each section of the beam comes from a restricted area of the mirror, and if any small area is defective, the distribution of light in the beam will be visibly influenced. A circular zone of angular defects results in either a bright or a dark ring, or both, in the beam. On account of this point-to-point correspondence between beam and mirror the surface accuracy of the hyperboloidal mirror must be high, often much higher than is the case with the paraboloidal mirror and the accuracy requirements are saved from becoming excessive only through the fact that the range of the spread beam is necessarily much less than that of the parabolic beam.

Some Fundamental Relations in the Hyperboloid

From the viewpoint of an illuminating engineer certain of the constants and variables connected with the hyperbola are of much greater importance than others. Thus, the generating angle of the curve is of more interest to him than the eccentricity, although the eccentricity is really the prime factor that determines nearly everything about the curve except its size or scale. The mathematician thinks and talks in terms of what to the reflector designer are the points of minor importance. As the text books are written by the mathematician, his viewpoint naturally prevails, and nowhere is this more evident than in the choice of co-ordinates. The mathematician habitually chooses rectangular co-ordinates while the designer is almost compelled to use polar co-ordinates, and the translation from one system to the other is not easy for the occasional user. But certain features about the reflector are more easily investigated by means of rectangular co-ordinates, and it therefore is well to use either polar or rectangular co-ordinates, according to which system best suits the purpose at hand. With this difference between the viewpoints of the engineer and the mathematician in mind, the following series of equations has been arranged so as to be more convenient for use by the former.

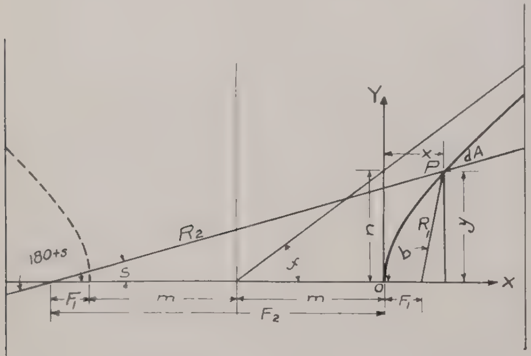


Fig. 167. The solid curve on the right is the generating curve of the concave hyperboloid referred to in the text, the light source being at the right-hand focus. This focal point is in general the pole of the polar co-ordinates while the line of the major axis and the tangent at the vertex form the X- and Y-axes of the rectangular system

Symbols (See Fig. 167):

b = the generating angle, positive in a clockwise direction.

F_1 = the focal length from vertex to interior focal point

F_2 = the focal length from vertex to external focal point

(x,y) = the rectangular co-ordinates of a point P on the curve, referred to the principal axis and the tangent at the vertex

s = the angle of spread from the axis of a ray through the point P, positive in a counter-clockwise direction

R_1 = the distance from the interior focus to the point P

R_2 = the distance from the exterior focus to the point P

m = half the difference between R_1 and R_2 (the semi-major axis)

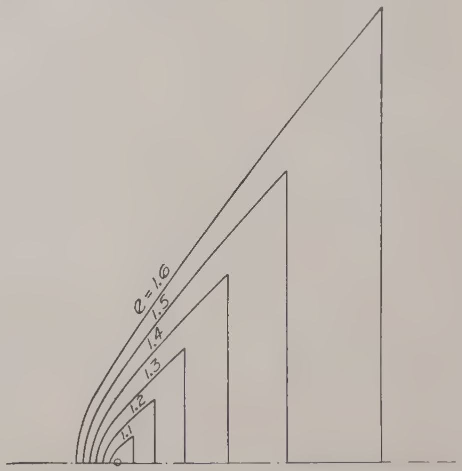


Fig. 168. The hyperbolas in this diagram are computed from constant values of m and collecting angle b, and a variable eccentricity as noted on the curves

n = the length of the tangent at the vertex, measured from the principal axis to the asymtote (the semi-minor axis)

f = the angle between the principal axis and the asymtote

e = the eccentricity (always greater than unity)

The hyperbola may be defined as the locus of a point moving so that the difference between its distances from two fixed points is constant

$$R_2 - R_1 = 2m \qquad (282)$$

The polar equation for a hyperbola is

$$R_1 = \frac{m\,(e^2-1)}{1+e\cos b} \qquad (283)$$

where R_1 is the distance to the adjacent concave curve so long as $1+e\cos b$ is positive, and when $1+e\cos b$ becomes negative, the distance is called $-R_2$, the negative sign being used because the measurement is now to the opposite convex curve. Using the exterior focus, Fig. 167, and calling the angle s positive in the counter-clockwise direction, we have

$$R_2 = -\frac{m\,(e^2-1)}{1-e\cos s} \tag{284}$$

the negative sign before $e\cos s$ being used because the generating angle in this case is really $180+s$ and $\cos s$ is therefore negative.

The focal length, F_1, requires a word of explanation. As ordinarily used, "focal length" denotes the position for parallel projection either by means of a mirror or a lens. But in the hyperbola "focal length" denotes that position that is conjugate to the other focal point. Thus when speaking of the curve of Fig. 167, the focal length to the right is called F_1, and we might therefore call the distance to the external focus F_2. There exists the simple relation

$$F_1 = m(e-1) \tag{285}$$

$$F_2 = m(e+1) \tag{286}$$

The eccentricity may be defined in terms of the other variables in a number of ways; as

$$e = \sec f \tag{287}$$

or, what is the same thing expressed in terms of m and n,

$$e = \frac{\sqrt{m^2+n^2}}{m} \tag{288}$$

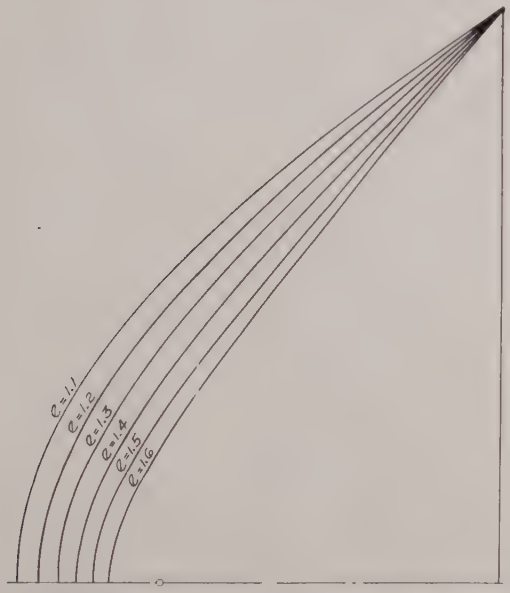


Fig. 169. These hyperbolas are computed to give equal diameters and equal collecting angles b. The eccentricity and semi-major axis m are variable so that b and y may be constant

A more useful expression for e when dealing in the projection of light is derived as follows:

The value of y, Fig. 167, is

$$y = R_1 \sin b = R_2 \sin s \tag{289}$$

Substituting from (283) and (284) we get

$$\frac{m\,(e^2-1)\sin b}{1+e\cos b} = -\frac{m\,(e^2-1)\sin s}{1-e\cos s} \tag{290}$$

and this gives

$$e = \frac{\sin b + \sin s}{\sin\,(b-s)} \tag{291}$$

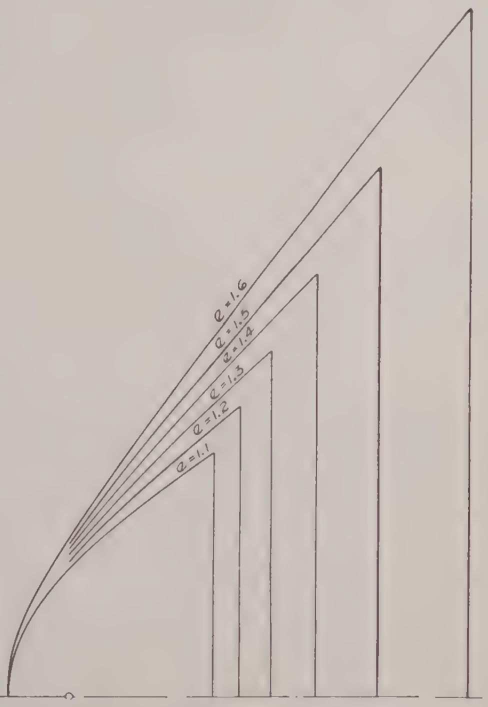


Fig. 170. At constant focal length F_1 and constant collecting angle b the diameters vary as shown when the eccentricity varies from 1.1 to 1.6

Distribution of Light from a Concave Hyperboloid

Confining our attention to point sources of light, the intensity of light reflected from a hyperbolic reflector is readily computed by assuming the source to be located at the conjugate focus, and then finding what change of intensity is caused by the altered solid angle of radiation.

In Fig. 167 consider a quantity of light dL to fall on a small area dA at the point P. From the focal point on the right, the solid angle subtended by this area is

$$dw_1 = \frac{dA\cos i}{R_1^2}\ \text{steradians} \tag{292}$$

where i is the angle of incidence. Also, from the left-hand focal point

$$dw_2 = \frac{dA \cos r}{R_2^2} \text{ steradians} \qquad (293)$$

The angle of reflection r is equal to the angle of incidence i, and hence

$$\frac{dw_1}{dw_2} = \frac{R_2^2}{R_1^2} \qquad (294)$$

The intensity of the incident light is

$$I_a = \frac{dL}{dw_1} \text{ candles} \qquad (295)$$

and, the coefficient of reflection being equal to K, the intensity of the reflected beam is

$$I_s = K\frac{dL}{dw_2} \text{ candles} \qquad (296)$$

Substituting the value of dL from (295) and then substituting $\left(\frac{R_2}{R_1}\right)^2$ from (294), the beam intensity in the direction of R_2 is

$$I_s = I_a K\left(\frac{R_2}{R_1}\right)^2 \text{ candles} \qquad (297)$$

It will be recalled that in solving for the beam from the paraboloidal mirror a sharp distinction was found to exist between the beams from points, spheres, and disks. In the particular case of the point source the beam could not be computed by the rules used for the other sources and furthermore the intensity in any given part of the beam from the finite sources was computable only by a careful exploration of the entire mirror area. Most of these distinctions and difficulties disappear when dealing with a hyperboloid, for here there is no bundle of parallel rays to lead to confusion in our conceptions of "beam candles," and each section of beam is almost entirely dependent on a single section of mirror. There is slight overlapping of the action of adjacent sections of mirror so that for a finite source the rule given by equation (297) is not exact, but the small degree of inexactness ordinarily removes the error from the consideration of the illuminating engineer.

The beam from a hyperboloidal mirror may in nearly all cases be computed directly by the aid of equation (297), along with a distribution curve showing the intensity of radiation, in candles, in all directions about the source—the surface brilliancy does not directly enter into the problem. This may be also stated by saying that the distribution of beam intensity is independent of the size and shape of the source. It will of course be realized that the independence here is not absolute, for a hyperboloid may be constructed so as to vary by only a small amount (e approximately equal to unity) from a paraboloid, and then the beam formation will vary from the true parabolic beam in only a small degree. This beam can be determined graphically by the methods used for the parabolic beam at short range, that is, a beam made up of bundles of rays whose axes do not coincide. The methods of applying this rule will not be gone into, particularly as the use of a nearly parabolic hyperboloid is rare.

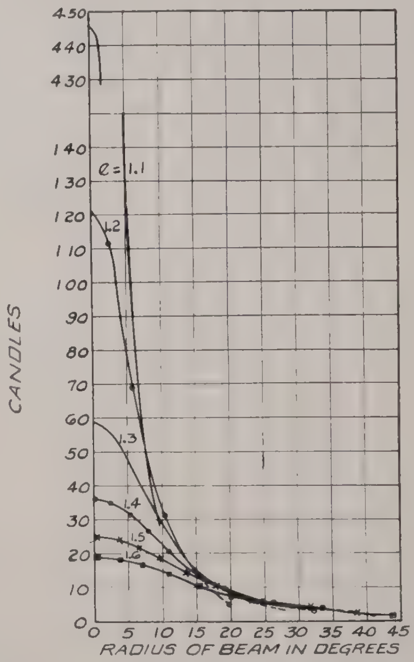


Fig. 171. These curves of beam intensities show the influence of the eccentricity upon the strength of the reflected light. As e approaches unity the beam approaches the truly parallel beam of the paraboloid with a point source. For large values of e the reflector becomes flatter and the beam intensity decreases at a rapid rate so that changing from $e = 1.1$ to 1.6 decreases the central beam strength to one twenty-third

The paraboloid will give a slightly dispersed beam by moving the source away from the focal point, and there is here a definite encroachment of the parabola onto the field of the hyperbola.

The hyperbolic beam may then be solved for, using equation (297) regardless of the size or shape of the source, except for the region at the edge of the beam, which does not have a perfectly sharp boundary, as the equation indicates.

Distribution of Light from a Convex Hyperboloid and a Point Source

All the various reflectors so far considered have concentrated the light into a beam of greater intensity than the radiation from the lamp. The convex hyperbola reverses this condition and the reflected light is more scattered and weaker than the direct radiation from the light source. The ratio of R_2 to R_1 is less than unity (where R_1 is the radius vector from the source and R_2 is the radius vector from the image) and the beam is weakest in the center and has a maximum strength, equal to that of the source, when reflected from the extreme edge of the reflector carried to infinity. The convex hyperboloid is therefore not a "projecting" device in the ordinary use of the word.

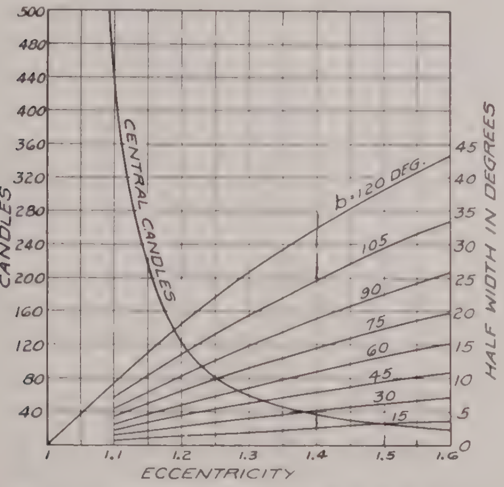


Fig. 172. The relation between central candles (from a one candle source) and the eccentricity of the hyperboloid is illustrated by the curve on the left. The family of curves on the right show the relation between the eccentricity, the collecting angle *b*, and the half-width of the beam

Increase of Intensity with Distance

With a point source the apparent intensity of the image is independent of the radius of photometric measurement. This follows from the independence of each section of a hyperboloidal mirror, for no change of distance along a radial line through the image will cause the addition (or subtraction) of adjacent active mirror sections. Something of the same condition held in the case of the point source and the paraboloidal, except that there the illumination was found to be constant at all distances while here the illumination varies inversely as the square of the distance; that is, the image source of the beam light seems fixed in intensity along any given radius from the image. Therefore, there is no increase of image intensity with distance.

Inverse-square Region

The space surrounding a bare lamp is all inverse-square region, for the illumination along any radial line varies inversely as the square of the distance. The hyperbolic beam coming as it does from an image of fixed intensity in any given direction is therefore in its entirety an inverse-square region, and illuminations at any distance may be directly computed from known illuminations at any other distance.

Testing Distance for Intensity

From the two preceding sections it is evident that a photometric exploration of the reflected light can be made at any desired distance, measuring the test distance of course from the image position.

Width of Beam

The width of beam is determined by the angle s measured about the conjugate focal point, and is therefore solely a function of the edge of the reflector. This will be recognized as just the reverse of the parabolic beam where the center of the mirror determined the beam spread. The ten per cent rule for beam width might be used to fix a definite width for the hyperboloidal mirror as determined by setting equation (297) equal to 0.10 and then solving for s.

Testing Distance for Width of Beam

The testing distance for width of beam is indeterminate, for every cross section resembles every other cross section in proportional intensity, and therefore any distance, measured from the image point, will do for measurement of the beam width.

Determination of Focal Position by Measuring Beam Width

The focusing of a hyperbolic beam can best be made by moving the light source along the axis until the beam is of the proper width, and moreover, if need be, the entire mirror can be explored for focal position by noting the position of the source for the correct angular projection of light from each mirror zone. This is a very practical test, and is easily carried out if the physical constants of the mirror are known.

Testing Distance for Entire Characteristic

A review of the various features of the hyperbolic beam from a point source shows in every case a complete independence of distance, so that, using the image point as the zero point, any concentric circle will give identical computed beam intensities, the intensity in each direction being of course equal to the observed illumination multiplied by the square of the radial distance.

(*To be continued*)

Notes on Ethereal Waves

By W. S. Andrews

General Engineering Laboratory, General Electric Company

Physicists today will tell you that they carry both the quantum theory and the wave theory of radiation around in their vest pockets, using one on the odd days of the month and the other on the even. Whichever theory succeeds in withstanding the final tests of time and research, for the time being we are best able to consider radiated energy in the light of waves propagated with a definite velocity already well known to science. Mr. Andrews has likened this great diapason of radiation to an enormous gamut of musical notes divided into octaves, and he tells us here of the physical characteristics by which each class of radiation is known.—Editor.

THE GAMUT OF RADIATION

There are no definite boundary lines between the different sections in the gamut of ethereal waves, such as the infra-red, visible, and ultra-violet spectra, for they all merge into each other like the colors in the visible spectrum.

Human vision differs individually to a small extent, for some people can detect visible light further into the infra-red or ultra-violet than others. In the case of nocturnal animals such as owls and bats, the limits of their visible spectrum must differ considerably from the human standard.

Some difference of opinion may exist as to the most convenient unit for expressing the wavelength (λ) of visible and ultra-violet radiation, but the Angstrom (A) has received international recognition, and the wavelength of the red line of cadmium, given as 6438.4696 A, is the accepted international standard(1). In some cases, however, the millimicron (mμ), equal to 10 Angstroms, may be preferred for convenience. The micron (μ) may be used for the measurement of wavelengths in the infra-red spectrum, and the millimeter and meter (mm and m) are suitable units for Hertzian waves, and waves used in wireless telegraphy. The relations between these units are well known, but are given in the following table for ready reference.

TABLE I

1 Angstrom (A)	=0.1	millimicron	$=10^{-8}$ cm.
10 Angstroms	=1	millimicron	$=10^{-7}$ cm.
1000 Millimicrons (mμ)	=1	micron	$=10^{-4}$ cm.
1000 Microns (μ)	=1	millimeter	$=10^{-1}$ cm.
10 Millimeters (mm)	=1	centimeter	
100 Centimeters (cm)	=1	meter	
1000 Meters (m)	=1	kilometer (km.)	

The maximum and minimum lengths of ethereal waves have no actual limits but for practical purposes our tabulation begins with a wavelength of 25,600 meters which is about the maximum used in wireless telegraphy. From this point it shows one unbroken gamut of about 53 octaves of continuously decreasing wavelengths, ending in the gamma rays of radium, which have been estimated down to the almost inconceivably minute length of 0.02 A.

The musical term "octave" is here used in connection with the scale of ethereal waves as a convenience, although its application is rather strained because the octaves of the ethereal gamut are not divided into eight parts corresponding to the eight tones in the musical octave. The term applied to the ethereal scale simply implies that the numerical values of the wavelengths are either halved or doubled in each succeeding octave, according to the direction in which the scale is read. Thus, for example, from 3600 A to 1800 A is one octave, or from 112.5 A to 3600 A equals five octaves.

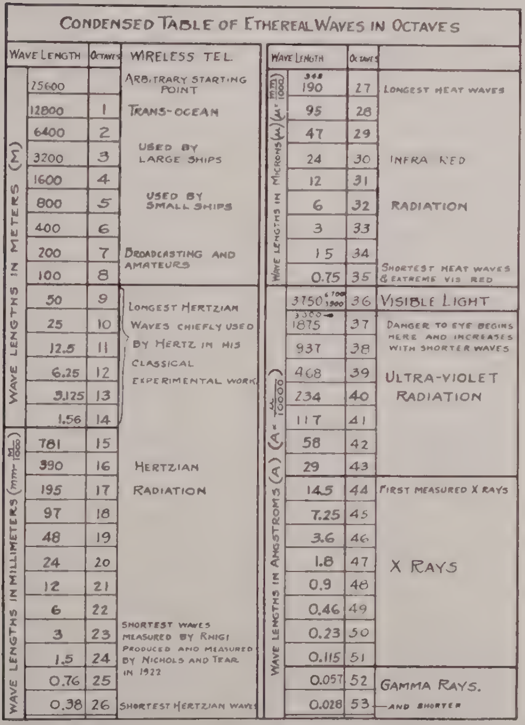
Beginning our tabulations, therefore, at a wavelength of 25,600 meters, as already stated, we find about eight octaves of diminishing wavelengths down to 100 m., all of which are more or less devoted to wireless telegraphy.

Starting again at 100 m., we enter the region of Hertzian radiation, which, up to a recent date, extended approximately fifteen octaves down to a wavelength of 3 millimeters, this being the length of the shortest wave measured by Rhigi. A gap of about three octaves of unexplored radiation was thus left between the shortest Hertzian waves and the longest wave in the dark heat or infra-red spectrum. This gap was, however, successfully investigated and closed up by the late Dr. E. F. Nichols and Dr. J. D. Tear of the Nela Research Laboratories, Cleveland, Ohio, in the latter part of 1922, by the application of exact methods to new and very sensitive instruments. In this way, these physicists were enabled to generate and measure ethereal waves in the Hertzian region down to less than half a millimeter, which is about the measure of the longest dark heat waves that were investigated by Rubens and Von Baeyer in 1911.

---

(1) Scientific Paper No. 414, Bureau of Standards, Washington, D. C. August 1, 1921.

The common origin and general features of these hitherto unknown waves were beautifully demonstrated by the fact that the instruments used for measuring the shortest of the Hertzian waves were also quite as effective for detecting and measuring the longest waves in the dark heat spectrum; and also, other devices which had been specially made for use in the dark heat or infra-red spectrum were found to be readily serviceable for measuring Hertzian waves.(2)



Condensed Table of Ethereal Waves in Octaves

	Wave Length	Octaves	Wireless Tel.		Wave Length	Octaves	
Wave lengths in meters (M)	25600		Arbitrary starting point	Wave lengths in microns (μ) ($\mu = \frac{mm}{1000}$)	343 190	27	Longest heat waves
	12800	1	Trans-ocean		95	28	
	6400	2			47	29	
	3200	3	Used by large ships		24	30	Infra red
	1600	4			12	31	
	800	5	Used by small ships		6	32	Radiation
	400	6			3	33	
	200	7	Broadcasting and amateurs		1 5	34	
	100	8			0.75	35	Shortest heat waves & extreme vis red
	50	9	Longest Hertzian waves chiefly used by Hertz in his classical experimental work	Wave lengths in Angstroms (A) ($A = \frac{\mu}{10000}$)	3750^{6700}_{3900}	36	Visible Light
	25	10			3300→ 1875	37	Danger to eye begins here and increases with shorter waves
	12.5	11			937	38	
	6.25	12			468	39	Ultra-violet radiation
	3.125	13			234	40	
	1.56	14			117	41	
Wave lengths in millimeters ($mm = \frac{M}{1000}$)	781	15			58	42	
	390	16	Hertzian radiation		29	43	
	195	17			14.5	44	First measured X rays
	97	18			7.25	45	
	48	19			3.6	46	
	24	20			1.8	47	X Rays
	12	21			0.9	48	
	6	22			0.46	49	
	3	23	Shortest waves measured by Rhigi		0.23	50	
	1.5	24	Produced and measured by Nichols and Tear in 1922		0.115	51	
	0.76	25			0.057	52	Gamma Rays.
	0.38	26	Shortest Hertzian waves		0.028	53	— and shorter

Fig. 1. **Graphic Representation of the Range of Ethereal Waves Divided into Octaves**

About three octaves were thus added to the Hertzian region which now totals about eighteen octaves.(3)

We now enter the spectrum of dark heat, or infra-red radiation, which begins at a wavelength of about 343 microns and extends approximately nine octaves, when it emerges to the average eye into the visible spectrum at a wavelength close to 6700 A.

The visible spectrum then continues to shine through the various colors of the rainbow for a little less than one octave to a wavelength of 4000 A, here fading gradually into twilight before vanishing into total invisibility in the ultra-violet at about 3900 A.

The ultra-violet spectrum was extended by Millikan down to the region of 112 A, which left a gap of a little more than three octaves of unknown radiation, between that point and the longest x-ray waves of about 12 A. In 1922, however, this hitherto unexplored region was investigated and mapped out by physicists in the Bureau of Standards at Washington, and also at Princeton University, N. J., by new and improved instruments of exact precision, so this last gap in the long gamut of 53 octaves may now be considered as satisfactorily closed.(4)

The x-ray spectrum which begins practically at a wavelength of 12 A continues for about seven octaves down to below 0.15 A, where in its turn it merges into the gamma ray spectrum of radium close to 0.071 A. The shortest wavelength that has been estimated in the gamma region up to this time is about 0.02 A.

In the light of these new and modern developments it is gratifying to note that all the former gaps of unknown waves have been explored and filled, from the longest waves that are used in wireless telegraphy, down to the gamma rays of almost incomprehensible minuteness, thus completely occupying a region of about 53 octaves as shown in Tables IIa, IIb, IIc, and IId. Fig. 1 gives a condensed table of the same sort in octaves, with a view to showing the entire gamut at a glance, and also the octaves contained in each division.

The following translation of an extract from *Bulletin de la Societe Française des Electriciens*, Vol. III, p. 28 (Feb., 1923), kindly furnished to the writer by Mr. L. A. Huguemont, illustrates a remarkable discovery in the mathematical determination of wavelengths in the x-ray region.

> "The minimum wavelength of x-rays depends on the voltage applied to the terminals of the x-ray tube. It can be calculated approximately by the formula:
>
> $\lambda_{\text{min.}} = \frac{12.34}{V}$ where $\lambda_{\text{min.}}$ = wavelength in Angstroms and V = kilovolts.
>
> The maximum wavelength for direct current is
>
> $\lambda_{\text{max.}} = 1.304 \left(\frac{12.34}{V}\right)$, and for alternating current is
>
> $\lambda_{\text{max.}} = 1.304 \left(\frac{12.34}{V}\right) + 0.05.$"

---

(2) Dr. Ernest Fox Nichols passed away while reading a paper entitled "Joining the Infra-red and Electric Wave Spectra" at the new headquarters of the National Academy of Science in Washington, April 29, 1924. The sad event is impressively described in the *Transactions of the Illuminating Engineering Society*, Vol. XIX, No. 6, p. 489, July 1924.

(3) A more detailed account of these original investigations may be found in "Science Supplement" of January 5, 1923, p.x.

(4) Further details relating to this interesting work may be found in the Annual Report of the Director of the Bureau of Standards, Washington, for year ending June 30, 1922, p. 86.

TABLE IIa

TABULATION OF ETHEREAL WAVES

Octaves	Wavelength	Wireless Radiation
8	Meters (m)	
	25,600	Arbitrary starting point
	24,000 10,000	Trans-ocean wireless
	3,200 2,200	Used by large ships
	600	Used by small ships
	400 100	Broadcasting stations and amateurs
		Hertzian Radiation
18	Meters (m)	
	50 1.5	Chiefly used by Hertz in his classical investigations
	millimeters (mm)	
	780	
	4	Shortest Hertzian waves measured by Lampa in 1897
	3	Measured by Rhigi
	microns (μ)	
	500 381.5	Measured by Nichols and Tear in 1923

THE VELOCITY OF ETHEREAL WAVES

The velocity of electrical waves through the ether of space is constant for all wavelengths, from those used in wireless telegraphy through the entire gamut to the almost infinitely minute gamma waves. This velocity is generally accepted as about

186,400 miles per second(5) or
299,981,721 meters per second, or nearly
300,000,000 meters per second, or
300,000 kilometers per second.

The velocity in air is about 50 miles or 80,000 meters per second lower than in a vacuum, and in denser media its speed is still less, and varies with different wavelengths, being less for blue light than for red.(6)

Through the vacuum of space, however, the velocity of all ethereal waves may be considered uniform as stated before.

TABLE IIb

TABULATION OF ETHEREAL WAVES (Cont'd)

Octaves	Wavelength	Infra-red or Dark Heat Radiation
9	Microns (μ)	
	343	Heat rays measured by Rubens and Von Baeyer in 1911
	30	Heat rays given off by the earth
	25	Sylvine in thin plates becomes opaque
	20	Rock salt ceases to transmit
	11	Fluorspar in thin plates is opaque
	5.5	Limit of heat rays measured by Langley
	2.7	Photographed by Abney in 1866
	0.75	Extreme red sometimes visible to acute vision
		Visible Light
Almost 1	Angstroms (A)	Note. — Bracket marks average limits of vision
	6700	Average limit of perception in red
	6310	Purest red
	5980	Purest orange
	5820	Purest yellow
	5310	Purest green
	4780	Purest blue
	4300	Purest violet
	3900	Limit of average sight in the violet
	3600	Extreme violet

NOTE.—The exact limits of vision naturally depend on the intensity of the light under observation, as well as on individual acuteness of sight.

The general formulas connecting the velocity, wavelength, and frequency of light waves are as follows:

When V = Velocity in kilometers per second
λ = Wavelength in millimicrons
n = Frequency in millions of millions per second,

then:

$V = \lambda n$, or Velocity = Wavelength × Frequency

$$\lambda = \frac{V}{n}, \text{ or Wavelength} = \frac{\text{Velocity}}{\text{Frequency}}$$

$$n = \frac{V}{\lambda}, \text{ or Frequency} = \frac{\text{Velocity}}{\text{Wavelength}}$$

---

(5) The latest measurement is 186,300 miles per second. See *Elec. Review, London*, November 21, 1924.

(6) From Optical Tables and Data (1900) by Sylvanus Thompson.

TABLE IIc

TABULATION OF ETHEREAL WAVES (Cont'd)

Octaves	Wavelength	Ultra-violet Radiation
	Angstroms (A)	
	3000	Danger line (to the eye) may be drawn here. Limit of solar spectrum in temperate regions
	2500	Dangerous effects increase rapidly from here with shorter wavelengths.
	2220	Clear quartz begins to absorb
	1800	Ozonizing begins
7	1700	Rock salt in thin plates ceases to transmit
	1350	Ionization of air begins
	1250	Limit of transmission in fine fluorite
	1000	Observed in spectrum of hydrogen (Schuman 1914)
	500	Observed in spectrum of helium (Lyman 1917)
	372 232 130	Observed in spectra of aluminum, magnesium and sodium by Millikan in 1921
	100 56.25 28.125	Measured by the Bureau of Standards, Washington, D. C., and Princeton University, N. J., in 1922

Examples:

What is the approximate frequency of the light waves that produce the bright yellow line in the spectrum of helium, the wavelength being roughly 5876 A or 587.6 millimicrons?

$\frac{V}{\lambda}=\frac{300,000}{587.6}=515$ millions of millions per second.

What is the approximate wavelength of the light shown in the bright red line of the hydrogen spectrum, its frequency being estimated at about 457.1 millions of millions per second?

$\frac{V}{n}=\frac{300,000}{457.1}=656.3$ millimicrons or 6563 A.

TABLE IId

TABULATION OF ETHEREAL WAVES (Cont'd)

Octaves	Wavelength	X-Rays and Gamma Rays
	Angstroms (A)	
	12.35	Longest x-rays from zinc observed by Freeman
10	0.122	Shortest measured x-rays (1917)
	0.071 0.02 and shorter	Gamma rays

APPROXIMATE SUMMARY OF TABLE II

Wireless Waves	8 octaves
Hertzian Waves	18 octaves
Infra-red Waves	9 octaves
Visible light Waves (nearly)	1 octave
Ultra-violet Waves	7 octaves
X-Rays and Gamma Rays	10 octaves
	53 octaves

THE TRANSPARENCY OF VARIOUS SUBSTANCES TO ULTRA-VIOLET RADIATION

The best specimens of clear colorless fluorite 1 to 2 mm. thick may transmit down to	1250 A
Crystalline quartz 0.2 to 0.3 mm. thick	1450 A
Crystalline quartz 2 mm. thick	1500 A
Crystalline quartz 20 mm. thick	1600 A
Rock salt 2 mm. thick	1770 A
Clear fused silica 0.3 to 0.4 mm. thick 24 per cent of	1849 A
Clear fused silica 0.3 to 0.4 mm. thick 36 per cent of	1970 A
Clear fused silica 0.3 to 0.4 mm. thick 40 per cent of	2000 A
Mica in thinnest possible leaf	3000 A
Common soda glass 2 to 3 mm. thick	3300 A
Common soda glass 0.2 mm. thick	2500 A
Shortest wavelength transmitted by a mercury lamp in a clear thin quartz tube	1849 A
A layer of pure water 10 mm. thick transmits to	2200 A
The mercury lamp in a glass tube is rich in waves between	2300 and 4000 A
An open disruptive spark between iron terminals is rich in waves between	1800 and 3380 A

—*From Hughes' Photo-electricity (1914), pp. 137-139.*

Revised Tables of Phase Angle Correction Factors for Use in Power Measurements

By C. T. Weller

General Engineering Laboratory, General Electric Company

An error occurs in measuring power in alternating-current circuits due to the phase displacements in the instrument transformers and in the wattmeter. If the phase displacements or phase angles are known, the error may be corrected and the true watts obtained by multiplying the preliminary result in apparent watts by the proper correction factor taken from the revised tables published in this article. These tables differ from those previously published in the following respects: the few errors that existed have been corrected, three columns of correction factors have been added, and the tables have been sectionalized, the two latter changes being made to facilitate interpolation. Directions for using the tables are given, together with formulas and other data useful in correcting the results of power measurements. Modifications of the formulas to make them applicable to the results of energy measurements made with watthour meters are also given.—Editor.

Introduction

An article on the Watthour Meter Method of Testing Current Transformers for Ratio and Phase Angle was published on page 642 of the July, 1921, issue of this magazine. In Tables I and II of that article were given correction factors for phase angle which had been published previously.(1) Mr. H. B. Brooks, of the Bureau of Standards, discovered that these tables contained a few errors. While the errors occurred in parts of the tables that are seldom used, it is nevertheless desirable to correct them. Mr. Brooks also found that in some places appreciable errors in interpolation might occur. This led to the addition of three columns of correction factors and to the sectionalizing of the tables. In the present article the tables appear in their revised and corrected form in accordance with the results obtained by Mr. Brooks.

The three columns of correction factors added are for apparent power-factors of 0.95, 0.99, and 1.00 respectively. These were added to facilitate interpolation between apparent power-factors of 0.90 and 1.00 and were not thought necessary when the tables were first compiled in 1909.(1)

The tables have been sectionalized in order to indicate where interpolation may be made without exceeding an arbitrary limit of error. The limit chosen was 0.0010 (10 units in the last place) in the correction factor $\left(\frac{\cos\theta}{\cos\theta_2}\right)$.

The error occurs in interpolating between adjacent values of apparent power-factor ($\cos\theta_2$); no error occurs in interpolating between adjacent values of phase angle ($\alpha+\beta+\gamma$). Interpolation is based on the assumption that the relation between the quantities involved is linear over the range in question. This assumption is, in general, correct with respect to the correction factor $\left(\frac{\cos\theta}{\cos\theta_2}\right)$ as a function of the phase angle ($\alpha+\beta+\gamma$); it is not in general correct with respect to the correction factor $\left(\frac{\cos\theta}{\cos\theta_2}\right)$ as a function of the apparent power-factor ($\cos\theta_2$). However, in the sections of the tables lying between the heavy black lines, the maximum error in correction factors, obtained by interpolation for any values of apparent power-factor lying between those given in the tables, will not exceed 0.0010. In the sections outside of the heavy black lines and in all cases where the adjacent values of $\cos\theta_2$ are separated by the heavy black lines, the maximum error in interpolation will exceed 0.0010. For example, when ($\alpha+\beta+\gamma$), the combined phase angle, is 1 deg. 10 min., interpolation may be made for any apparent power-factors lying between 0.25 and 0.30, but not for some apparent power-factors lying either between 0.20 and 0.25 or between 0.30 and 0.40, without exceeding an error of 0.0010. Curves may be plotted for different values of ($\alpha+\beta+\gamma$), with values of apparent power-factor ($\cos\theta_2$) as abscissae and of correction factor $\left(\frac{\cos\theta}{\cos\theta_2}\right)$ as ordinates, for use in interpolating between adjacent apparent power-factors in the sections of the tables lying outside of the heavy black lines and in all cases where the adjacent values of $\cos\theta_2$ are separated by the heavy black lines.

Directions for the use of the tables, in connection with the calculations pertaining to the watthour meter method of testing current transformers for ratio and phase angle, are given in the article referred to.

---

(1) See Electrical Measurements on Circuits Requiring Current and Potential Transformers, by L. T. Robinson, *Transactions of the A.I.E.E.*, vol. 28, 1909, p. 1005.

The tables were first compiled to correct wattmeter readings for phase angle. Directions for this application of the tables are given herewith for convenient reference, together with other pertinent data.

Directions for Using the Tables

The principal convention that has been adopted relates to the signs of the different phase angles. A phase angle is considered to be positive (plus) if it increases the reading of a wattmeter on lagging power-factor and negative (minus) if it decreases the reading.

The formula for true watts when current and potential transformers are used is as follows:

$$\text{True watts} = WR \times \frac{\cos\theta}{\cos\theta_2} \times CT \times PT \qquad (1)$$

where WR = wattmeter reading corrected for scale error
$\cos\theta$ = true power-factor
$\cos\theta_2$ = apparent power-factor
CT = true ratio of current transformer
PT = true ratio of potential transformer

Also,

$$\theta = \theta_2 + (\alpha + \beta + \gamma) \qquad (2)$$

where α = phase angle of wattmeter
β = phase angle of current transformer
γ = phase angle of potential transformer

and

$$\cos\theta_2 = \frac{WR^*}{AR \times VR} \qquad (3)$$

where AR = ammeter reading corrected for scale error
VR = voltmeter reading corrected for scale error

The angle θ is considered to be positive for lagging current and negative for leading current. Equation (2) represents an algebraic sum. The algebraic sum $(\alpha+\beta+\gamma)$ rarely exceeds 2 degrees and is frequently less than 30 minutes. Angle α is usually positive and not greater than 5 minutes at 60 cycles. Angle β is usually positive. Angle γ may be either positive or negative.

At or near unity power-factor, the value of the correction factor $\left(\frac{\cos\theta}{\cos\theta_2}\right)$ differs only slightly from unity and therefore has little effect on the result. At low power-factors, however, $\frac{\cos\theta}{\cos\theta_2}$ may differ appreciably from unity, in which case a considerable error would result if it were neglected.

The following procedure for determining the correction factor applies to all power measurements made with a single-phase wattmeter, irrespective of whether the circuit is single-phase or polyphase. (It should be noted, however, that in some polyphase measurements, such as, for example, the use of the two-wattmeter method on a three-phase circuit, the power-factor on the individual wattmeters is different from the circuit power-factor and may have the opposite sign; that is, it may be leading instead of lagging and vice-versa.)

(a) Obtain α, the equivalent phase angle of the wattmeter, from the wattmeter certificate.
(b) Obtain β, the phase angle between the primary and (reversed) secondary currents of the current transformer, from the transformer certificate at the burden used and at the secondary current read on the ammeter.
(c) Obtain γ, the phase angle between the primary and (reversed) secondary voltages of the potential transformer from the transformer certificate at the burden used and at the secondary voltage read on the voltmeter.
(d) Add algebraically α, β and γ, using the correct signs as determined from the convention adopted.
(e) Calculate $\cos\theta_2$, using formula (3).
(f) Select the correction factor from Tables I or II.

Table I should be used either when the phase angle $(\alpha+\beta+\gamma)$ is a positive angle and the current in the circuit supplying the wattmeter is lagging or when $(\alpha+\beta+\gamma)$ is a negative angle and the current is leading. Table II should be used either when $(\alpha+\beta+\gamma)$ is a positive angle and the current is leading or when $(\alpha+\beta+\gamma)$ is a negative angle and the current is lagging.

In both tables, a set of values of $(\alpha+\beta+\gamma)$, the combined phase angle, is given in the left-hand column. On the first line across the top of the columns is given a set of values of $\cos\theta_2$, the apparent power-factor. The correction factor $\left(\frac{\cos\theta}{\cos\theta_2}\right)$ is found in the column under the proper apparent power-factor, opposite the proper value of $(\alpha+\beta+\gamma)$. Interpolation should be used when necessary, as outlined.

The correction factor obtained should be inserted in formula (1). If certificates are not available, an approximate correction factor may be obtained by neglecting α and by taking β and γ from characteristic curves of the instrument transformers.

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*Formula (3) applies only when the ammeter is connected in series with the wattmeter current circuit, and the voltmeter is connected in multiple with the wattmeter potential circuit.

It is always possible to determine the value of $\frac{\cos\theta}{\cos\theta_2}$ from a table of cosines, by using the relation shown by formula (2); for the highest precision, this method should be used instead of interpolating to obtain values of $\frac{\cos\theta}{\cos\theta_2}$ corresponding to any values of $\cos\theta_2$ lying between those given in the tables.

The procedure outlined for single-phase wattmeters may also be applied to polyphase wattmeters, providing that the polyphase circuit is balanced and that the instrument transformers have similar characteristics. Formula (3) should be modified by substituting polyphase watts and polyphase volt-amperes for the corresponding single-phase quantities.

The procedure outlined for measurements of power using single and polyphase wattmeters may also be applied to measurements of energy using the corresponding watthour meters when operating at practically constant load. This condition does not often exist. The per cent accuracy of the watthour meter under the load condition includes the effect of any phase displacement in the meter (corresponding to α for a wattmeter) as well

TABLE I

CORRECTION FACTORS $\left(\frac{\cos\Theta}{\cos\Theta_2}\right)$ FOR PHASE ANGLE

For Lagging Current when $(\alpha+\beta+\gamma)$ is Positive
For Leading Current when $(\alpha+\beta+\gamma)$ is Negative

(Revised March, 1925)

Phase Angle $(\alpha+\beta+\gamma)$	APPARENT POWER-FACTOR ($\cos\Theta_2$)													
	0.10	0.15	0.20	0.25	0.30	0.40	0.50	0.60	0.70	0.80	0.90	0.95	0.99	1.00
5′	0.9855	0.9904	0.9929	0.9944	0.9954	0.9967	0.9975	0.9981	0.9985	0.9989	0.9993	0.9995	0.9998	1.0000
10′	0.9711	0.9808	0.9857	0.9887	0.9907	0.9933	0.9950	0.9961	0.9970	0.9978	0.9986	0.9990	0.9996	1.0000
15′	0.9566	0.9712	0.9786	0.9831	0.9861	0.9900	0.9924	0.9942	0.9955	0.9967	0.9979	0.9986	0.9994	1.0000
20′	0.9421	0.9616	0.9715	0.9775	0.9815	0.9867	0.9899	0.9922	0.9940	0.9956	0.9972	0.9981	0.9992	1.0000
25′	0.9276	0.9520	0.9643	0.9718	0.9768	0.9833	0.9874	0.9903	0.9926	0.9945	0.9965	0.9976	0.9989	1.0000
30′	0.9131	0.9424	0.9572	0.9662	0.9722	0.9800	0.9848	0.9883	0.9911	0.9934	0.9957	0.9971	0.9987	1.0000
40′	0.8842	0.9232	0.9429	0.9549	0.9629	0.9733	0.9798	0.9844	0.9881	0.9912	0.9943	0.9961	0.9983	0.9999
50′	0.8552	0.9040	0.9286	0.9436	0.9536	0.9666	0.9747	0.9805	0.9851	0.9890	0.9929	0.9951	0.9978	0.9999
1° 0′	0.8262	0.8848	0.9143	0.9323	0.9444	0.9599	0.9696	0.9766	0.9820	0.9868	0.9914	0.9941	0.9974	0.9998
10′	0.7972	0.8656	0.9000	0.9209	0.9350	0.9531	0.9645	0.9726	0.9790	0.9845	0.9899	0.9931	0.9969	0.9998
20′	0.7682	0.8464	0.8857	0.9096	0.9257	0.9464	0.9594	0.9687	0.9760	0.9823	0.9885	0.9921	0.9964	0.9997
30′	0.7392	0.8271	0.8714	0.8983	0.9164	0.9397	0.9543	0.9648	0.9730	0.9800	0.9870	0.9911	0.9959	0.9997
40′	0.7102	0.8079	0.8571	0.8869	0.9071	0.9329	0.9492	0.9608	0.9699	0.9778	0.9855	0.9900	0.9954	0.9996
50′	0.6812	0.7886	0.8428	0.8756	0.8978	0.9262	0.9441	0.9568	0.9668	0.9755	0.9340	0.9890	0.9949	0.9995
2° 0′	0.6521	0.7694	0.8284	0.8642	0.8884	0.9194	0.9389	0.9529	0.9638	0.9732	0.9825	0.9879	0.9944	0.9994
10′	0.6231	0.7501	0.8141	0.8529	0.8791	0.9127	0.9338	0.9489	0.9607	0.9709	0.9810	0.9869	0.9939	0.9993
20′	0.5941	0.7308	0.7997	0.8415	0.8697	0.9059	0.9287	0.9449	0.9576	0.9686	0.9795	0.9858	0.9934	0.9992
30′	0.5650	0.7115	0.7854	0.8301	0.8603	0.8991	0.9235	0.9409	0.9545	0.9663	0.9779	0.9847	0.9928	0.9990
40′	0.5360	0.6923	0.7710	0.8187	0.8510	0.8923	0.9183	0.9369	0.9515	0.9640	0.9764	0.9836	0.9923	0.9989
50′	0.5069	0.6730	0.7566	0.8073	0.8416	0.8855	0.9132	0.9329	0.9483	0.9617	0.9748	0.9825	0.9917	0.9988
3° 0′	0.4779	0.6537	0.7422	0.7959	0.8322	0.8787	0.9080	0.9288	0.9452	0.9594	0.9733	0.9814	0.9912	0.9986
10′	0.4488	0.6344	0.7279	0.7845	0.8228	0.8719	0.9028	0.9248	0.9421	0.9570	0.9717	0.9803	0.9906	0.9985
20′	0.4198	0.6151	0.7135	0.7731	0.8134	0.8651	0.8976	0.9208	0.9390	0.9547	0.9701	0.9792	0.9900	0.9983
30′	0.3907	0.5957	0.6991	0.7617	0.8040	0.8583	0.8924	0.9167	0.9359	0.9523	0.9686	0.9781	0.9894	0.9981
40′	0.3616	0.5764	0.6847	0.7503	0.7946	0.8514	0.8872	0.9127	0.9327	0.9500	0.9670	0.9769	0.9888	0.9980
50′	0.3326	0.5571	0.6702	0.7388	0.7852	0.8446	0.8820	0.9086	0.9296	0.9476	0.9654	0.9758	0.9882	0.9978
4° 0′	0.3035	0.5378	0.6558	0.7274	0.7758	0.8377	0.8767	0.9046	0.9264	0.9452	0.9638	0.9746	0.9876	0.9976
10′	0.2744	0.5185	0.6414	0.7160	0.7663	0.8309	0.8715	0.9005	0.9232	0.9429	0.9622	0.9735	0.9870	0.9974
20′	0.2453	0.4991	0.6270	0.7045	0.7569	0.8240	0.8663	0.8964	0.9201	0.9405	0.9605	0.9723	0.9864	0.9971
30′	0.2163	0.4798	0.6125	0.6930	0.7474	0.8171	0.8610	0.8923	0.9169	0.9381	0.9589	0.9711	0.9857	0.9969
40′	0.1872	0.4604	0.5981	0.6816	0.7380	0.8103	0.8558	0.8882	0.9137	0.9357	0.9573	0.9699	0.9851	0.9967
50′	0.1581	0.4411	0.5837	0.6701	0.7285	0.8034	0.8505	0.8841	0.9105	0.9333	0.9556	0.9687	0.9844	0.9964
5° 0′	0.1290	0.4217	0.5692	0.6586	0.7191	0.7965	0.8452	0.8800	0.9073	0.9308	0.9540	0.9675	0.9838	0.9362
10′	0.0999	0.4024	0.5548	0.6472	0.7096	0.7896	0.8400	0.8759	0.9041	0.9284	0.9523	0.9663	0.9831	0.9959
20′	0.0708	0.3830	0.5403	0.6357	0.7001	0.7827	0.8347	0.8717	0.9008	0.9260	0.9507	0.9651	0.9824	0.9957

Interpolation for correction factors corresponding to values of $(\alpha+\beta+\gamma)$ lying between those given in the table, may be made without error. Interpolation for correction factors corresponding to values of $\cos\Theta_2$ lying between those given in the table, may be made without exceeding an error of 0.0010 in the sections of the tables lying between the heavy black lines; outside of these sections, and in all cases where the adjacent values of $\cos\Theta_2$ are separated by the heavy black lines, the maximum error in interpolation will exceed 0.0010.

as the effect of friction, etc., and formula (1) becomes:

$$\text{True watthours} = DR \times \frac{100}{A} \times \frac{\cos\theta}{\cos\theta_2} \times CT \times PT \qquad (4)$$

where DR = watthour meter dial reading
A = per cent accuracy under load conditions
$\theta = \theta_2 + (\beta + \gamma)$, since A includes α.

The other factors are the same as before.

The readings of indicating instruments should be used in formula (3) to determine the power-factor.

In many cases, the wattmeter scale and the watthour meter register take into account the nominal or marked ratios of the instrument transformers, so that the readings are in terms of the primary circuit (kilowatts or kilowatt-hours, respectively). The formulas then include the $\frac{\text{true ratios}}{\text{marked ratios}}$ or the ratio correction factors instead of the true ratios of the instrument transformers and formulas (1) and (4) become, respectively, (1A) and (4A):

$$\text{True kilowatts} = WR' \times \frac{\cos\theta}{\cos\theta_2} \times \frac{TR_c}{MR_c} \times \frac{TR_p}{MR_p} \qquad (1A)$$

$$\text{True kilowatt-hours} = DR' \times \frac{100}{A} \times \frac{\cos\theta}{\cos\theta_2} \times \frac{TR_c}{MR_c} \times \frac{TR_p}{MR_p} \qquad (4A)$$

TABLE II

CORRECTION FACTORS $\left(\frac{\cos\Theta}{\cos\Theta_2}\right)$ FOR PHASE ANGLE

For Lagging Current when $(\alpha+\beta+\gamma)$ is Negative
For Leading Current when $(\alpha+\beta+\gamma)$ is Positive

(Revised March, 1925)

Phase Angle $(\alpha+\beta+\gamma)$	APPARENT POWER-FACTOR (COS Θ_2)													
	0.10	0.15	0.20	0.25	0.30	0.40	0.50	0.60	0.70	0.80	0.90	0.95	0.99	1.00
5′	1.0145	1.0096	1.0071	1.0056	1.0046	1.0033	1.0025	1.0019	1.0015	1.0011	1.0007	1.0005	1.0002	1.0000
10′	1.0289	1.0192	1.0142	1.0113	1.0092	1.0067	1.0050	1.0039	1.0030	1.0022	1.0014	1.0010	1.0004	1.0000
15′	1.0434	1.0288	1.0214	1.0169	1.0139	1.0100	1.0075	1.0058	1.0044	1.0033	1.0021	1.0014	1.0006	1.0000
20′	1.0579	1.0383	1.0285	1.0225	1.0185	1.0133	1.0101	1.0077	1.0059	1.0043	1.0028	1.0019	1.0008	1.0000
25′	1.0723	1.0479	1.0356	1.0281	1.0231	1.0166	1.0126	1.0097	1.0074	1.0054	1.0035	1.0024	1.0010	1.0000
30′	1.0868	1.0575	1.0427	1.0338	1.0277	1.0200	1.0151	1.0116	1.0089	1.0065	1.0042	1.0028	1.0012	1.0000
40′	1.1157	1.0766	1.0569	1.0450	1.0369	1.0266	1.0201	1.0154	1.0118	1.0087	1.0056	1.0038	1.0016	0.9999
50′	1.1446	1.0958	1.0711	1.0562	1.0461	1.0332	1.0251	1.0193	1.0147	1.0108	1.0069	1.0047	1.0020	0.9999
1° 0′	1.1735	1.1149	1.0853	1.0674	1.0553	1.0398	1.0301	1.0231	1.0177	1.0129	1.0083	1.0056	1.0023	0.9998
10′	1.2024	1.1340	1.0995	1.0787	1.0645	1.0464	1.0351	1.0269	1.0206	1.0151	1.0097	1.0065	1.0027	0.9998
20′	1.2313	1.1531	1.1137	1.0898	1.0737	1.0530	1.0400	1.0308	1.0235	1.0172	1.0110	1.0074	1.0030	0.9997
30′	1.2601	1.1722	1.1279	1.1010	1.0829	1.0596	1.0450	1.0346	1.0264	1.0193	1.0123	1.0083	1.0034	0.9997
40′	1.2890	1.1913	1.1421	1.1122	1.0921	1.0662	1.0500	1.0384	1.0292	1.0214	1.0137	1.0091	1.0037	0.9996
50′	1.3178	1.2104	1.1562	1.1234	1.1012	1.0728	1.0549	1.0421	1.0321	1.0235	1.0150	1.0100	1.0040	0.9995
2° 0′	1.3466	1.2294	1.1704	1.1346	1.1104	1.0794	1.0598	1.0459	1.0350	1.0256	1.0163	1.0109	1.0044	0.9994
10′	1.3755	1.2485	1.1845	1.1457	1.1195	1.0859	1.0648	1.0497	1.0379	1.0276	1.0176	1.0117	1.0047	0.9993
20′	1.4043	1.2675	1.1986	1.1569	1.1286	1.0925	1.0697	1.0535	1.0407	1.0297	1.0189	1.0126	1.0050	0.9992
30′	1.4331	1.2866	1.2127	1.1680	1.1377	1.0990	1.0746	1.0572	1.0435	1.0318	1.0202	1.0134	1.0053	0.9990
40′	1.4618	1.3056	1.2268	1.1791	1.1469	1.1055	1.0795	1.0610	1.0464	1.0338	1.0215	1.0142	1.0055	0.9989
50′	1.4906	1.3246	1.2409	1.1902	1.1560	1.1120	1.0844	1.0647	1.0492	1.0359	1.0227	1.0150	1.0058	0.9988
3° 0′	1.5194	1.3436	1.2550	1.2013	1.1650	1.1185	1.0893	1.0684	1.0520	1.0379	1.0240	1.0158	1.0061	0.9986
10′	1.5481	1.3626	1.2691	1.2124	1.1741	1.1250	1.0942	1.0721	1.0548	1.0399	1.0252	1.0166	1.0063	0.9985
20′	1.5768	1.3816	1.2832	1.2235	1.1832	1.1315	1.0990	1.0758	1.0576	1.0419	1.0265	1.0174	1.0066	0.9983
30′	1.6056	1.4005	1.2972	1.2346	1.1923	1.1380	1.1039	1.0795	1.0604	1.0439	1.0277	1.0182	1.0068	0.9981
40′	1.6343	1.4195	1.3113	1.2456	1.2013	1.1445	1.1087	1.0832	1.0632	1.0459	1.0289	1.0190	1.0071	0.9980
50′	1.6630	1.4384	1.3253	1.2567	1.2103	1.1509	1.1136	1.0869	1.0660	1.0479	1.0301	1.0197	1.0073	0.9978
4° 0′	1.6916	1.4573	1.3393	1.2677	1.2194	1.1574	1.1184	1.0906	1.0687	1.0499	1.0313	1.0205	1.0075	0.9976
10′	1.7203	1.4763	1.3533	1.2788	1.2284	1.1638	1.1232	1.0942	1.0715	1.0519	1.0325	1.0212	1.0077	0.9974
20′	1.7489	1.4952	1.3673	1.2898	1.2374	1.1703	1.1280	1.0979	1.0742	1.0538	1.0337	1.0220	1.0079	0.9971
30′	1.7776	1.5141	1.3813	1.3008	1.2464	1,1767	1.1328	1.1015	1.0770	1.0558	1.0349	1.0227	1.0081	0.9969
40′	1.8062	1.5329	1.3953	1.3118	1.2554	1.1831	1.1376	1.1052	1.0797	1.0577	1.0361	1.0234	1.0083	0.9967
50′	1.8348	1.5518	1.4092	1.3228	1.2644	1.1895	1.1424	1.1088	1.0824	1.0596	1.0373	1.0241	1.0085	0.9964
5° 0′	1.8634	1.5707	1.4232	1.3337	1.2733	1.1959	1.1472	1.1124	1.0851	1.0616	1.0384	1.0248	1.0086	0.9962
10′	1.8920	1.5895	1.4371	1.3447	1.2823	1.2023	1.1519	1.1160	1.0878	1.0635	1.0396	1.0255	1.0088	0.9959
20′	1.9205	1.6083	1.4510	1.3557	1.2912	1.2086	1.1567	1.1196	1.0905	1.0654	1.0407	1.0262	1.0089	0.9957

Interpolation for correction factors corresponding to values of $(\alpha+\beta+\gamma)$ lying between those given in the table, may be made without error. Interpolation for correction factors corresponding to values of cos Θ_2 lying between those given in the table, may be made without exceeding an error of 0.0010 in the sections of the tables lying between the heavy black lines; outside of these sections, and in all cases where the adjacent values of cos Θ_2 are separated by the heavy black lines, the maximum error in interpolation will exceed 0.0010.

Where WR' = wattmeter reading (in primary terms) corrected for scale error

DR' = watthour meter dial reading (in primary terms)

$\frac{TR_c}{MR_c} = \frac{\text{true ratio}}{\text{marked ratio}}$ or ratio correction factor of current transformer

$\frac{TR_p}{MR_p} = \frac{\text{true ratio}}{\text{marked ratio}}$ or ratio correction factor of potential transformer.

The other factors are the same as before.

Example of Application

The application of the tables and the formulas to the results of a power measurement is given in the following example:

The data are from a single-phase measurement at lagging power-factor using a current transformer having a marked or nominal ratio of 200:1 and a potential transformer having a marked or nominal ratio of 100:1.

***Test Data:** Secondary Instrument Readings:*

Volts	Amp.	Watts	Wattmeter Phase Angle
113	4.8	255	
Instrument Corrections from Certificates (at corresponding values):			
−1.0	+0.1	+1.0	+3 min.
Corrected Readings			
112	4.9	256	

Data from Transformer Certificates (at the secondary burdens used):

CURRENT (AT 4.9 AMP.)		POTENTIAL (AT 112 VOLTS)	
True Ratio	Phase Angle	True Ratio	Phase Angle
(200×0.9960):1 =199.2:1	+6 min.	(100×0.9970):1 =99.7:1	−3 min.

***Calculations:** For Phase Angle Correction Factor:*

$\alpha+\beta+\gamma=+3+6-3=+6$ min.

From (3), $\cos\theta_2=\frac{256}{112\times4.9}=0.4665.$

From Table I, by interpolation, the correction factor is 0.9967 as shown below:

	0.40	0.50	0.4665 = cos θ_2
5′	0.9967	0.9975	
10′	0.9933	0.9950	
6′	0.9960	0.9970	0.996665 (=0.9967)

Substituting in (1)

True watts = 256×0.9967×199.2×99.7 = 5,067,400

Substituting in (2)

θ = +62 deg. 12 min. + 6 min. = +62 deg. 18 min.

$\cos\theta=0.4648$

θ_2 and $\cos\theta$ were obtained from a table of cosines.

The data may be summarized as in Table III.

TABLE III

	True	Apparent
Watts*	5,067,400	5,120,000
Power-factor*	0.4648 (cos θ)	0.4665 (cos θ_2)
Cur. Tr. Ratio	(200×0.9960†):1 =199.2:1	200:1
Pot. Tr. Ratio	(100×0.9970†):1 =99.7:1	100:1
Overall Ratio	(20,000×0.9930†):1 = 19,860:1	20,000:1

* After instrument corrections.

† $\frac{\text{True ratios}}{\text{Marked ratios}}$ or ratio correction factors.

The overall ratio correction factor is 0.9960×0.9970 = 0.9960×(1−0.0030) = 0.9930 and the overall phase angle correction factor is 0.9967; this gives an overall correction factor of 0.9930 × 0.9967 = 0.9930 × (1 − 0.0033) = 0.9897. In other words, the overall correction is 1.03 per cent (minus) to the nearest 0.01 per cent, which should be applied to the apparent watts to obtain the true watts.

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Condensed references to some of the more important articles in the technical press, as selected by the G-E Main Library, will be listed in this section each month. New books of interest to the industry will also be listed. In special cases, where copy of an article is wanted which cannot be obtained through regular channels or local libraries, we will suggest other sources on application.

Air Compressors
Development of the Turbo-Compressor. Carrard.
Brown Boveri Rev., Jan., 1925; v. 12, pp. 3-8.
(On the various means of improving their efficiency.)

Arc Welding
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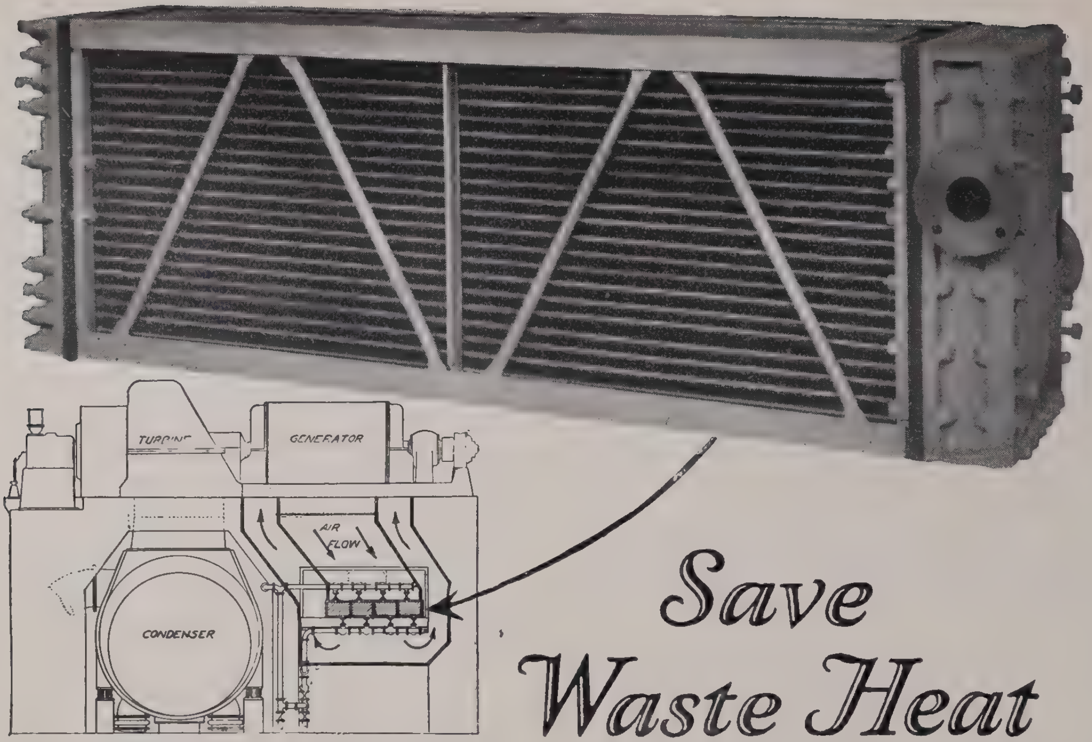

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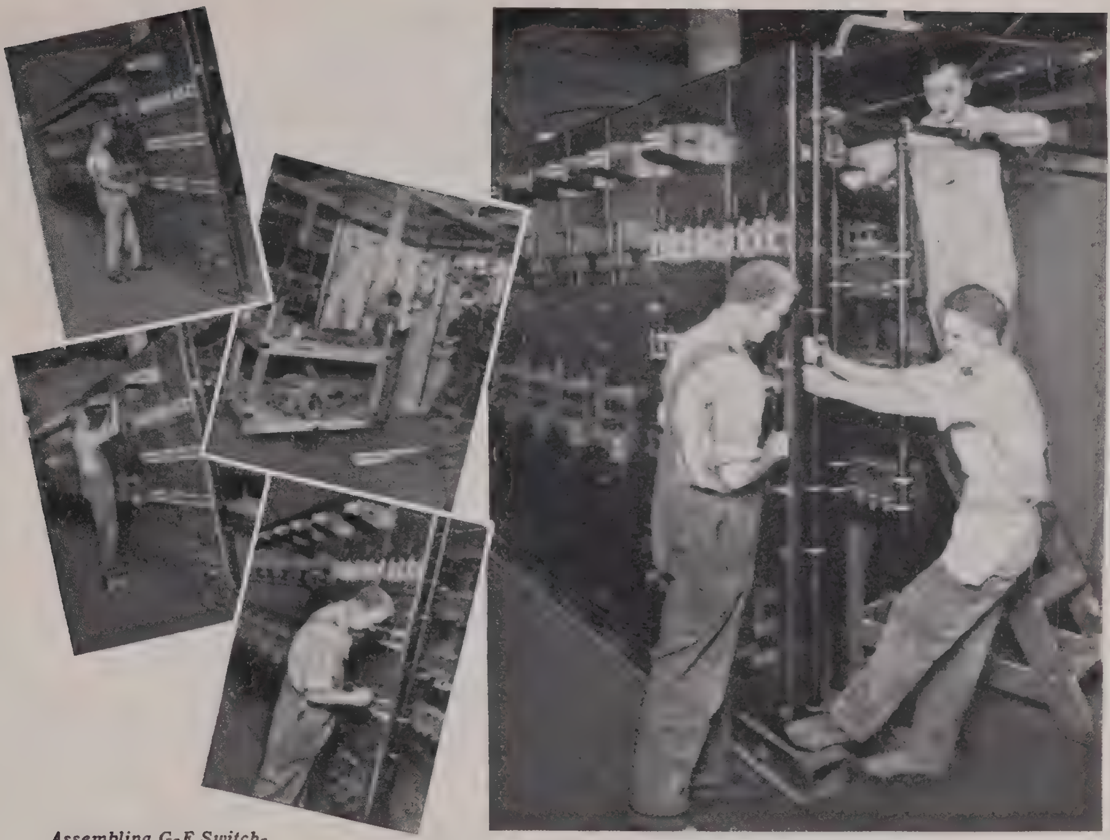

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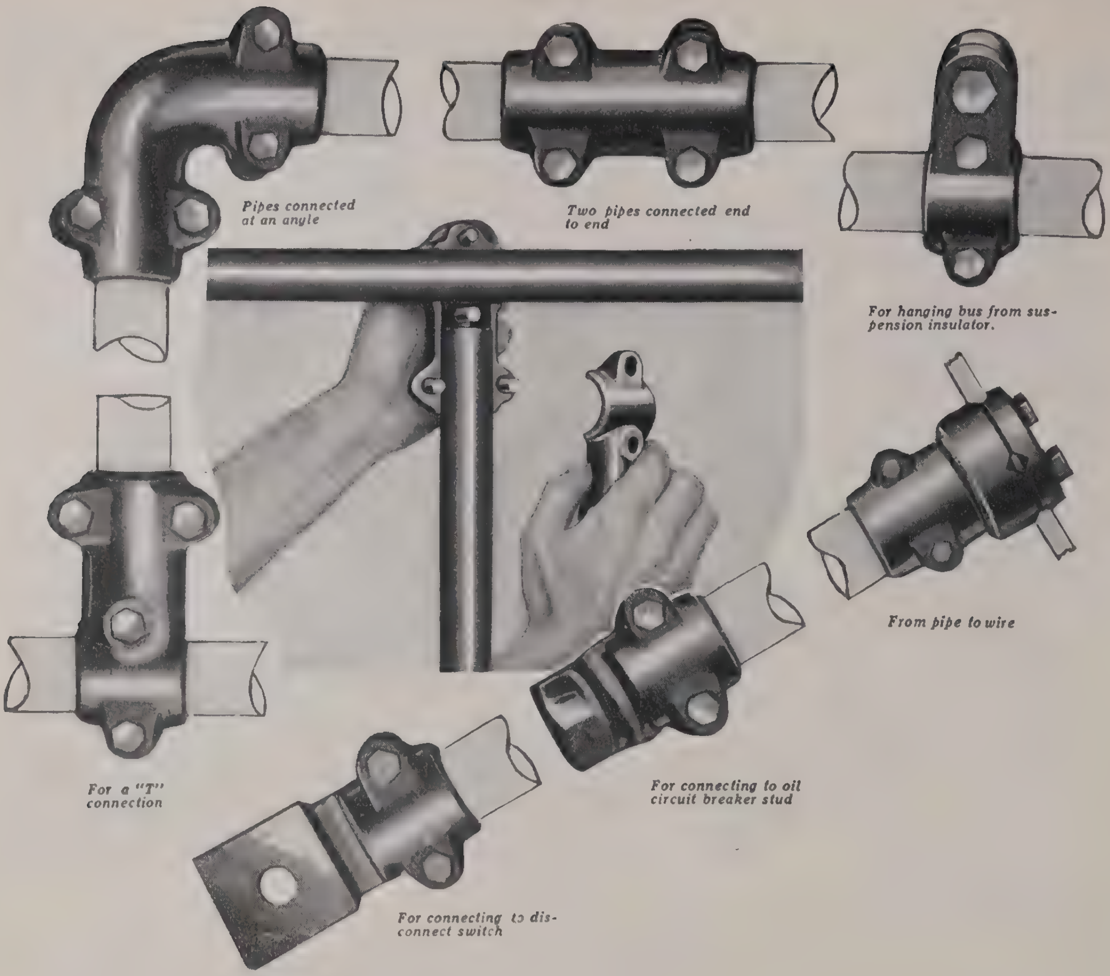
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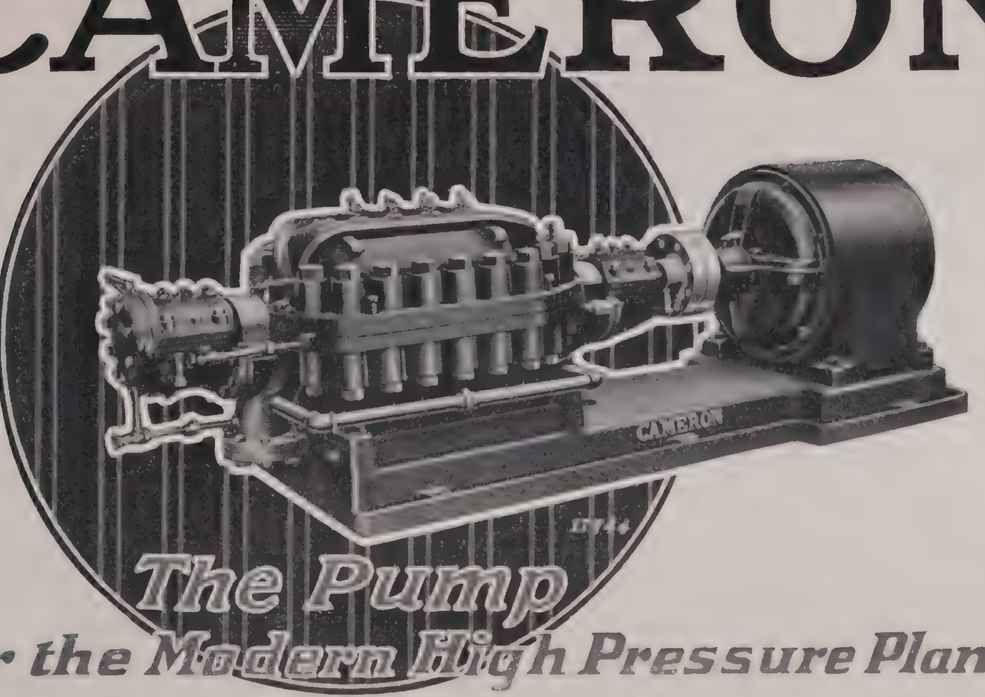

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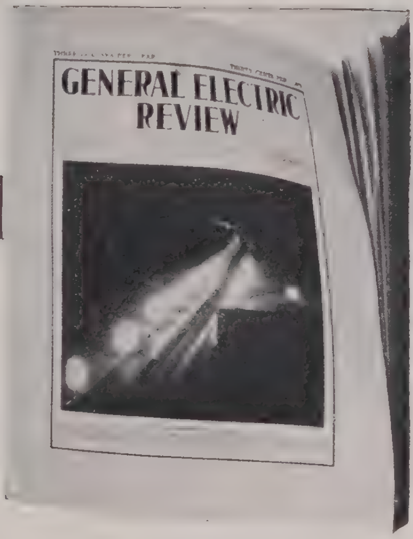

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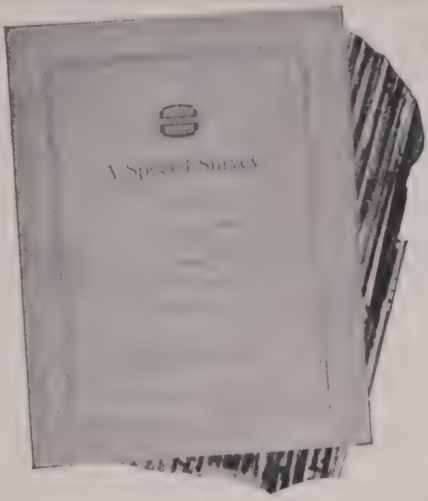

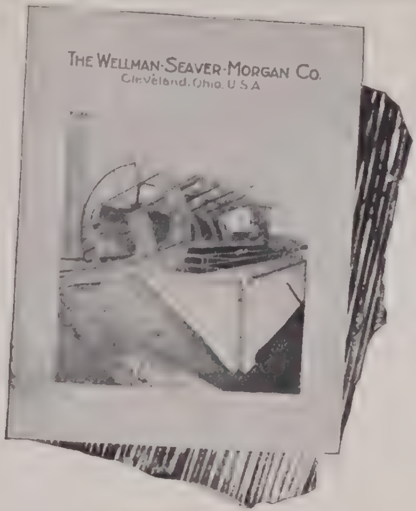

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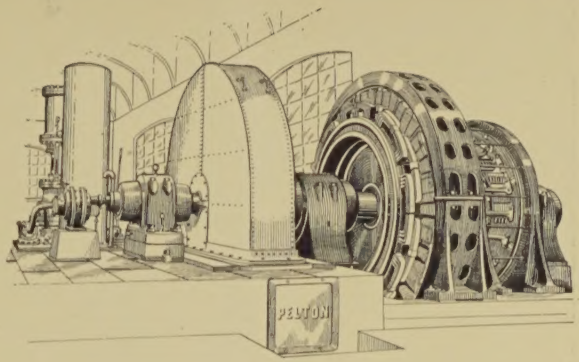

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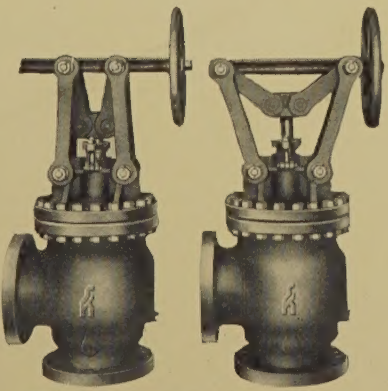
Cast steel body—Monel mounted

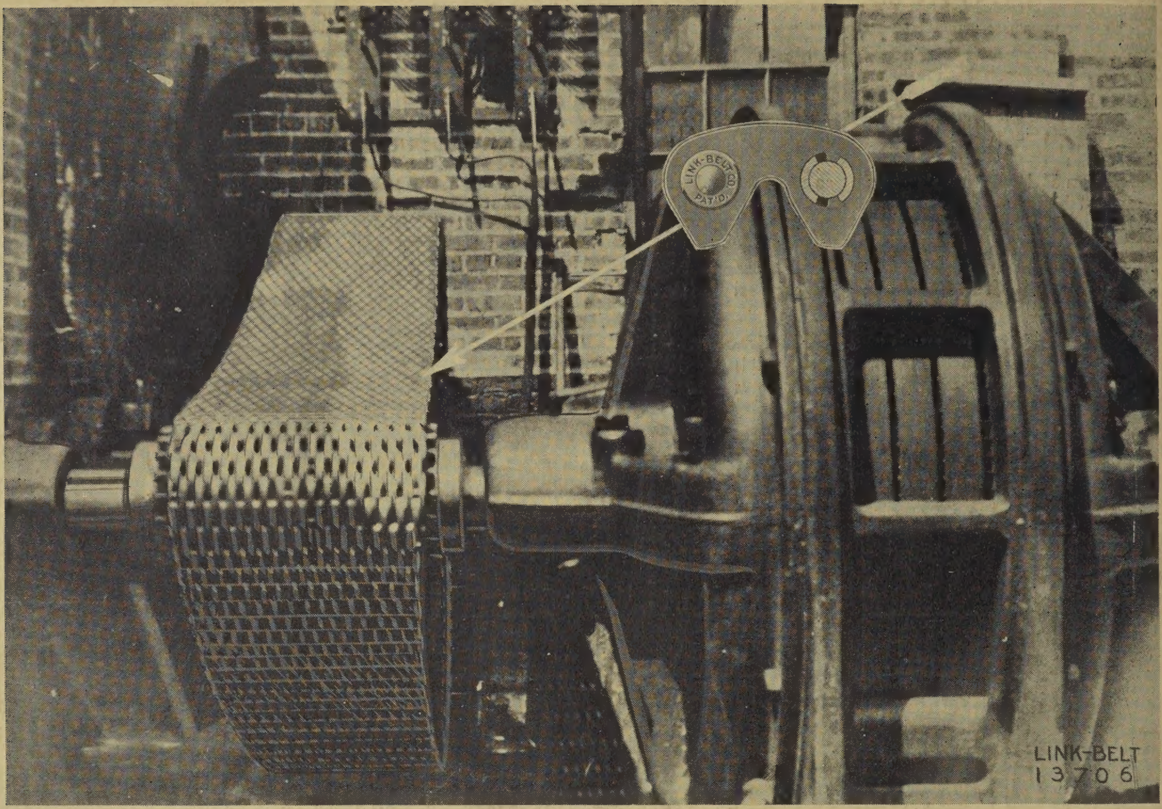
Special features include toggle arrangement for closing against boiler test pressure, unloading rod reducing weight of spool, cooling chamber around spindle, special seat threads, etc.



Closed and open position of Toggle Top Stop Check Valve

Ask Valve Department for Bulletin 8-B

SCHUTTE KOERTING
1196 THOMPSON STR
PHILADELPHIA·PA



Link-Belt Silent Chain operating fan at Bell & Zoller Mining Co., Ziegler, Ill.

Continuity of Operation Assured

CHAINED to a 200-h.p. G-E motor by a Link-Belt Silent Chain Drive, *this* mine fan may be relied on to deliver a constant, uniform quantity of life-giving air. Absolute dependability of performance has made Link-Belt Silent Chain the *preferred* Drive for Fans, Pumps, Lineshafts, and other work where continuity of operation is vital.

Other reasons for selecting Link-Belt Silent Chain are readily given by those who have used this drive for years. Sustained, 98.2% efficiency (on actual test); ability to run at relatively high speeds; short center distance possible; lessened journal friction, and minimum of attention required; freedom from all trouble from heat, cold, dryness or moisture — these are cogent reasons for using Link-Belt Silent Chain Drives. Due to the saving in power alone, they usually pay for themselves several times over. Write nearest Link-Belt Office for details.

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LINK-BELT

50 THIS YEAR LINK-BELT IS FIFTY YEARS OLD

SILENT CHAIN DRIVES